AUSTRALIAN MEAT PROCESSOR CORPORATION

Options to Maximise Process Heat Recovery at Red Meat Processing Facilities

Project code:	2013/5011
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Date published:	January 2015
Published by:	Australian Meat Processor Corporation

AMPC acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

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1.0 Executive Summary

1.1 Subject and Background

Snowy Mountains Engineering Corporation (SMEC) prepared this paper on behalf of Australian Meat Processor Corporation (AMPC) under the 2013 round of research funding under the environment, sustainability and climate change related research. The research brief was entitled 'Examination of options to maximise process heat recovery at red meat processing facilities'.

Over recent years a number of emerging technologies and technology variants have entered the industrial heat and power market, and AMPC recognised a knowledge gap in this space. AMPC has sought to improve knowledge to ensure the Australian red meat processing industry benefits from viable technological advancements.

This research paper provides guidance to industry on a variety of known and emerging technologies that are deployable and readily available in Australia. However, the technologies are not necessarily mainstream technology in the heat recovery elements of the red meat processing industry. This paper identifies technology that could enhance red meat processing facility heat recovery, and thus benefit facility efficiency and lead to improvements in financial performance.

The project methodology included a literature review, four preliminary feasibility studies involving AMPC member sites and a detailed feasibility study.

1.2 Technological Results

Research results indicate there are numerous technological improvements in heat production and recovery available, which could be both practical and commercially attractive.

The case study indicated that three different forms of heat and power technologies could deliver strong financial returns in the five- to seven-year rate of return (RoR) range as stand-alone investments, including:

- gas engine cogeneration
- micro-turbine modular cogeneration
- organic rankine cycle (orc) cogeneration.

The stand-out technology investigated for application to red meat processing facilities was the modular and adaptable micro-turbine cogenerator, while further technology development in modular ORC cogenerators demands monitoring.

Additionally, three other technologies were examined that could, under the right physical circumstances, provide attractive technical and financial returns, but which were not particularly suited to the feasibility case study. These include:

- gas turbine cogeneration
- exhaust gas absorption chilling
- waste heat absorption chilling.

Each of these technologies delivered technical benefits but provided particularly long investment return periods in the case study undertaken on feasibility levels.

1.3 Capital Competition

The research also found that there is extremely tight competition for capital expenditure programs within the red meat processing industry. In many cases capital programs are required to deliver rates of return (RoR) of two years or under, inclusive of financing costs. The research also indicates that capital works programs look at RoR as the prime decision driver, rather than internal rate of return (IRR) or the longer-term investment comparative net present value (NPV) tool. NPV is certainly relevant to major overhaul optioneering considerations, but it is not regularly used on annual capital programs.

We reviewed technology investment opportunities against tight capital competition. The research indicates that an investment hurdle RoR of two years cannot be met by the examined heat recovery technology upgrade/integration initiatives as stand-alone capital investments.

The research does indicate that when a heat recovery project is incorporated into a major overhaul or asset replacement project, suitable investment hurdles are achieved and technology can be improved.

1.4 Funding Options

Another research finding is that the modular equipment lends itself to non-capital funding programs such as commercial leases, commercial hire purchase and vendor financing. There are four key reasons that distinct benefits can be derived using this form of funding for this form of technology:

- The funding does not interfere with an otherwise overflowing capital program, and the expense incurred is an operational expense rather than capital, regardless of vendor financing, lead or hire-purchase arrangements.
- The modular nature of the equipment means that the scale of the equipment rollout over time with ‘bolt-on’ capacity expansion can be controlled.
- The vendors are seeking to establish these new technologies in the Australian market and therefore are inclined and ready to provide vendor financing. Potentially, vendor financing could match cost reductions to lease payments, delivering cash flow neutral or slight positives during the lease period, with a small balloon payment due at the end of the agreement.

1.5 Recommendations

We highly recommend further research into integrating new technologies into scheduled plant upgrades, along with field trials of modular micro-turbine and ORC heat and power equipment.

2.0 Process Undertaken

A multi-stage research project was commissioned by AMPC and has resulted in three separate research papers being delivered, which are Appendices A, B and C to this paper.

2.1 Literature Review

Undertaking a review of existing literature helped develop an understanding of the available documentation and research previously undertaken by published researchers and engineering providers. Prior research relating to steam turbines along with co/tri-generation systems were the primary focus. Other technologies that were of interest to the red meat processing facilities were absorption chillers and their viability within the industry.

2.2 In-situ Boiler Review

To develop a clear understanding of technologies currently in operation throughout a range of red meat processing facilities around Australia, we investigated four sites and reviewed their processes. The primary goal of attending each facility was to determine what technologies could possibly be integrated into the facilities. As every business is different in how they operate and manage their facilities, factors such as ease of integration and payback periods had to be considered, along with the concern of additional capital and operational costs. We suggested potential upgrades and possible process alterations to an approximate ±30% model for each of the facilities.

2.3 Technology Review

The technology review was undertaken in conjunction with the literature review and was incorporated into the literature review report. The results of the technology review and the subsequent research into optioneering for the case studies undertaken in the in-situ boiler review and the detailed feasibility study fed into the investigations and cost–benefit analysis for the detailed feasibility study.

The technology review identified six potential technologies for use in heat recovery improvement projects. It also excluded further serious investigations into steam turbines in red meat processing facilities.

2.4 Detailed Feasibility Study

One facility was selected based upon the in-situ boiler review along with their potential to implement the proposed suggestions. This involved further technology investigation, informed by the technology review and greater knowledge of the facility's operations and financial investment parameters. A range of six suggested projects was priced to a ±5% investment cost, while a steam turbine was also considered and rejected as a viable option.

A full financial comparison model was developed including RoR, IRR and NPV comparison tools. This analysis covered previously suggested upgrades along with additional options of interest to the facility.

3.0 Project Objective

AMPC has recognised that a future issue for the red meat processing industry is the rapidly rising cost of boiler feed sources. These feedstocks generally involve electricity or gas (natural or LPG), and in Queensland commonly involve overburden coal. In some country locations that have co-located timber industries, biomass boilers using woodchips or sawdust are in place. This rising feedstock cost is causing red meat processing businesses to reassess the way in which they generate, consume and recover energy at their facilities. That energy, for the purpose of this research, is specifically aimed at heat and the potential to recover waste heat.

Boiler systems in established meatworks can be oversized and incorporate technology that has been surpassed or superseded.

In many cases, abattoirs have been redeveloped from humble beginnings based around an original core of technology, including the boiler systems. Other technology advances have been made within the plants, reducing steam generation needs and improving steam efficiency.

New technologies and processes are available that are far more efficient and effective. These technologies present the opportunity to reuse steam, recover waste heat, utilise excess heat for cooling applications or upgrade boiler technology completely.

This project examined these technologies and process options, as well as developing a thorough understanding of the potential to utilise steam turbines to harness excess output for large boiler plants that are not viable to change out.

The primary objective of this project was to examine technologies currently available to the red meat processing industry to enhance the facility's efficiency and final product. Future R&D identification is a key output of this research, ensuring the Australian red meat processing industry is at the forefront of viable technological advancements.

4.0 Milestones Achieved

Literature review:

- documented steam system options and their fuels
- explained commercially available technologies to new-built and retrofit applications
- documented feasibility implications and operational implications of the new technology options
- investigate the viability of steam turbines to generate electricity
- documented publicly published reviews, articles and case studies from Australia and worldwide.

Boiler review:

- conducted site visits to four facilities across NSW and Queensland
- conducted interviews with facility operators managers
- documented current boiler equipment
- documented actions already taken in heat recovery
- documented technological challenges faced by the plant operators
- documented attitudes towards new technologies, in particular absorption chillers.

Technology review:

- documented the technologies currently available in heat recovery, and heat and power systems
- identified suitable applications for the viable technologies
- documented technology deployment cost
- developed +/- 30% case studies at four red meat processing facilities involving heat recovery or cogeneration implementation options.

Detailed feasibility study:

- completed feasibility case study to +/-5% of a number of heat recovery/cogeneration options for a red meat processing facility
- identified further R&D required for these technologies.

5.0 Results

5.1 Steam Turbines

Informed by the literature and in-situ boiler reviews, the technology review initially investigated the potential for steam turbines to be utilised in modern red meat processing facilities. However, the research found that the modern applications for steam turbines tend to require high-volume, high-pressure steam and an ample supply of waste biomass as the fuel, such as a sugar mill, rather than a low-volume, hot-water, low-pressure application that has minimal immediately combustible biomass, which is typical of a red meat facility.

Additionally, red meat processing facilities that have biomass of quantity have, typically, implemented covered anaerobic lagoons or other biogas digesters to process the biomass into gaseous form for use in boilers on site.

As a result, steam turbine applications in the red meat processing industry were found to be very rare, and tended to be 'grandfathered' technology rather than recent developments, as the technology has been predominantly superseded by gas-fired turbines.

Of the four sites visited, with one studied in significant depth, and in light of the evidence of the literature review, we found that it is highly unlikely that steam turbines will be a viable or technically adept option for heat recovery improvements in existing red meat facilities that currently do not already utilise the technology via biomass firing.

There was no evidence uncovered that further R&D into steam turbines would deliver viable options in the future.

5.2 Installed Equipment

The four sites visited during the in-situ boiler review ranged from state-of-the-art facilities to those that had been in operation for a number of years and had been augmented over time.

Plant A heat production equipment:

- three gas-fired efficient boilers in good condition
- one tri-generation power (2mw), steam and hot water unit (pending commissioning at the time of site visit).

Plant B heat production equipment:

- three gas-fired efficient boilers in good condition.

Plant C heat production equipment:

- coal-fired fluidised bed boiler producing steam and, via a heat exchanger, warm water and hot water
- cooker flue stack heat exchanger producing hot water.

Plant D heat production equipment:

- two gas-fired boilers operating with 'warm' inlet bore water
- flue gas heat exchanger on rendering plant.

5.3 Heat or Energy Recovery Actions Already Taken

Plant A:

- a new tri-generation unit producing significant power output along with hot and warm water has been installed.

Plant B:

- this site is a reasonably recently constructed site with modern gas boilers.

Plant C:

- this site is considered a state-of-the-art meat processing facility, however primary process heating is provided by an aging fluidised bed boiler.

Plant D:

- the installation of a covered anaerobic lagoon (CAL) is in process at this site.

5.4 Heat Recovery Technology Opportunities Identified

5.4.1 Recognised Technologies

Two technologies that were identified as viable and attractive enough to investigate further are widespread, well-known technologies in general industry and in the meat processing industry in Australia. These are:

- gas engine cogeneration
- gas turbine cogeneration.

The research shows that each of these two technologies is deployed in similar applications, while they have specific strengths in heat and/or power production, and are therefore suited to the varying output needs of the individual site operators.

Gas engines provide heat and power options highly suited to red meat processing facilities, with turbines suited to applications where high-pressure steam is needed.

Of the four red meat processing facilities visited, hot water and low-pressure steam were the key process heat needs.

5.4.2 Advancing Technologies

We also identified four potential technologies for use in red meat processing facilities, which are less well known in the meat industry and have few deployments to physically observe or study at this point.

They are, however, relatively well known among other heat and power applications, such as the coal-seam gas industry and in industrial-scale refrigeration operators such as food transport and storage. These are:

- micro-turbine modular cogeneration
- organic rankine cycle (orc) cogeneration
- exhaust gas absorption chilling
- waste heat absorption chilling.

Research indicates that the additional cost and larger physical attributes of absorption chillers over basic electrical units means that they are mostly deployed in greenfield custom-designed major refrigeration systems. Rarely are they deployed as a brownfield replacement for small- to medium-scale heat recovery.

It was also found that micro turbines and ORC cogenerators are both emerging technologies that are very modular and expandable in nature. As a result, they are highly applicable to brownfield expansion and augmentation, especially where process space is at a premium in an older facility.

5.5 Detailed Feasibility Study

From the four red meat processing facilities visited, Plant D was selected as the best test case for a feasibility study of a number of technologies for technology/need match and cost benefit, to ascertain the relative merits or otherwise of the installation of heat recovery technology into the existing operational plant.

The reasons for selecting Plant D include:

- Spatially, Plant D was not physically constrained in the plant room area of the site, allowing the potential for augmentation or addition of equipment.
- The site has the physical scale to allow adequate consideration of a steam turbine as a heat recovery option.
- Plant D has substantial electricity purchase costs that could be ameliorated by on-site power generation.
- Plant D has existing natural gas supplies and is implementing biogas recovery works from the anaerobic lagoon.
- There was an identified potential project to replace boiler capacity with a cogeneration unit, with the additional potential to displace all boiler capacity on site.
- We identified emerging technologies in the cogeneration and absorption-chiller field, which had strong potential at the site. This provided multiple optionality in the research and the potential to take an additional step into tri-generation, harnessing excess steam for refrigeration.
- Plant D has steam and power needs that are typical of large red meat facilities reviewed previously, so it provided a good case study for the industry.

A range of six suggested projects was priced to a ±5% investment cost, while a steam turbine was also considered and rejected as a viable option.

The comprehensive financial comparison model utilised delivered financial comparisons on RoR, IRR and NPV.

We analysed a number of projects suggested during the site visits, some raised by the site operator and some identified by the technology review as emerging technologies.

Table 1: Technology match against red meat processing need

TECHNOLOGY	CAPITAL INTENSITY	FEEDSTOCK MARCH	APPLICATION MARCH	MODULAR	INTEGRATION DIFFICULTY	FINANCIAL ATTRACTIVE
Steam Turbine	High	Poor	Poor	No	Yes	No
Gas Engine Cogen	Very High	Strong	Strong	No	Yes	Yes

Gas Turbine Cogen	Very High	Strong	Poor	No	Yes	Not at these sites
Exhaust Gas Absorption Chiller	Low	Moderate	Strong	Yes	Low	Moderately
Waste Heat Absorption Chiller	Low	Moderate	Strong	Yes	Low	Moderately
Micro-Turbine Cogen	Moderate	Strong	Strong	Yes	Low	Yes
ORC Cogen	Low	Strong	Strong	Yes	Low	Not at this time

The micro-turbine cogeneration option was the stand-out performer from the technology and cost–benefit analysis. It provides a strong feedstock/need match, has moderate capital intensity, delivers high-efficiency power and steam, is modular to match variant site needs and offers ease of installation, while also being the most financially attractive with an IRR of 23.5%.

The potential for installing a gas engine cogeneration plant is another attractive option with similar 23% returns and feedstock/need matches. However, such an option in an operation plant is likely to present significant integration difficulties, production downtime, and it is highly capital intensive.

The developed ranking matrix summarises the relative attractiveness of each of the options considered.

- An overall rating of 1.5 to 2 delivered an investment-ready solution with a two-year RoR.
- A weighted score of 1 w
- as considered to be a technology of worth that may attract third-party funding under acceptable terms and conditions.
- Anything less than 1 was unlikely to attract immediate investment in the red meat processing industry.

Table 2: Matrix Summary

MATRIX SUMMARY	
Micro-Turbine	1.0
ORC Recovery Unit	0.8
Absorption Chiller – Exhaust	0.6
Engine	0.5
Absorption Chiller – Waste Heat	0.5
Turbine	0.1

5.6 Capital Financing Constraints

Each of the operators interviewed identified capital competition as a particular issue within the red meat processing industry. The interviewees stated that capital investment expectations can require IRRs of around 50% or better to attract the available capital.

As a result there is a myriad of projects that are not funded each year within the industry, despite their relative commercial attractiveness in comparison to engineering projects in other industries, such as the utilities and infrastructure industries.

Research also indicated that capital works programs look at RoR as the prime decision driver, rather than IRR or the longer-term investment comparative NPV tool. NPV is certainly relevant to major overhaul optioneering considerations, but it is not regularly used on annual capital programs.

We also identified that projects with capital values of over $5M for the replacement of plant that had not reached the end of its operational life span were unlikely to be supported. This was mainly because the scale of the project would block numerous other attractive investments across the entire company.

5.7 Coincident Installation

The research indicates that when a heat recovery project is incorporated into major overhauls or asset replacement projects, suitable investment hurdles are achieved and technology improvement over the status quo can be delivered.

There is therefore potential for a heat recovery project to reach the two-year RoR hurdle when it is combined with a planned major works replacement of existing plant that has reached the end of its useful life.

The early identification of design options for major plant replacement is therefore a critical intervention point for the introduction of heat recovery and cogeneration technologies.

5.8 Funding Options

An identified potential for modular equipment is that it lends itself to non-capital funding programs such as commercial leases, commercial hire purchase and vendor financing. There are four key reasons that distinct benefits can be derived using this form of funding for this form of technology:

- The funding source does not interfere with an otherwise overflowing capital program, and the expense incurred is an operational expense rather than capital, regardless of vendor financing, lead or hire-purchase arrangements.
- The modular nature of the equipment means that the scale of the equipment rollout over time with ‘bolt-on’ capacity expansion can be controlled.
- The vendors are seeking to establish these new technologies in the Australian market and therefore are inclined and ready to provide vendor financing.
- Potentially, vendor financing could match cost reductions to lease payments, delivering cash flow neutral or slight positives during the lease period, with a small balloon payment due at the end of the agreement.

There is very strong potential for third-party investment to be attracted to returns exceeding 15%. Commercial leasing or vendor finance are obvious choices in return for 10-year rental contracts that provide the funder with a strong return and do not affect processing facility capital works programs.

The likelihood of long-term firm 10-year rental/lease contracts can also mean penalty clauses for early termination are likely. These penalty clauses could be commercially concerning to processing facilities that have some risk of limited life spans or that need a major overhaul in the next decade to keep pace with technology changes in the industry.

6.0 Recommendations for Further Research and Development

6.1 Micro-Turbine Installation Trials

There is clear merit in the emerging micro-turbine cogenerator technology and given their modular nature, the development aspect of trialling units in the field at red meat processing facilities could enable a significant market rollout.

We strongly recommend that AMPC consider a development project delivering a functional operational test of modular micro-turbine cogenerators at a significantly sized red meat processing facility that has expansion needs due to capacity growth, with the micro turbine hybridised to existing boiler plant.

6.2 ORC Cogeneration Development

There is clear merit in the emerging ORC technology; however, at this time the available units are not of sufficient scale to provide a useful alternative to boiler technology.

The potential in ORC cogeneration technology is the development of larger units that can delivery modularity at a cost much reduced from the 2014 delivery and output costs.

We recommend that AMPC consider further R&D projects with the ORC cogeneration industry to develop and trial an ORC unit that has direct application to red meat processing facilities.

6.3 Overhaul Integration

A key learning from this research is that many major investments in heat recovery need to be delivered during overhauls or major maintenance change-out works, where investment is already underway and can be diverted to cogeneration works. Such cogeneration works will be a far more attractive proposition than simple boiler replacement at the change-out site.

Retrofit of major plant such as boilers with cogeneration equipment, prior to the end of their effective life, is simply an unviable exercise in an environment where competition for capital is fierce.

6.4 Capital Outsourcing

The competition for capital within the red meat processing industry is a clear blockage for the delivery of more efficient heat production within processing facilities.

Accessing alternative funding sources, including recognition from financiers of the merits of the emerging technologies and the well understood gas-engine/turbine options is essential.

We recommend that AMPC consider a development project, working with technology suppliers and the asset investment community, to develop investment-ready vendor and third-party leasing/hire-purchase products. This activity would include de-risking the technology applications and counter-parties for interested investors relating to heat recovery technologies.

7.0 Appendices

Appendix A: Literature Review Heat Recovery in Steam Generation in Red Meat Processing Facilities

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1.0 Executive Summary

There are a number of different ways for the red meat processing industry participants to improve plant energy usage efficiency in relation to steam generation. These techniques can help to provide both environmental and economic benefits for the facility, while upgrading technology to modern standards.

This paper reviews literature on the feed sources and the various types of boilers including coal, oil/diesel, gas (natural, methane, LPG), biomass as well as new methods of efficient steam production (such as co/tri-generation systems) and ways of harnessing the energy contained in excess steam production.

There are three main options that are apparent from the review:

- Replace old boilers, potentially coal fired, with more modern natural gas and biogas fired boilers. The associated emission reductions, availability, cost and technical challenges need to be addressed when analysing any choice of boiler fuel, however if it is readily available then natural gas is a leading option. A gas system can be supplemented with biogas captured from an anaerobic wastewater treatment process located onsite.

- Retrofit or install a new co-generation system. Co-generators are generally gas-fired and allow for the simultaneous production of steam and power, thus reducing the dependence on utility supplied power and replacing standalone boilers. A cogeneration system can be sized to either meet the thermal energy usage or the electrical energy usage for the site, or both. They become viable when the potential site has high annual operating hours, at least 500kW average electricity demand, a yearly thermal load of 2000 GJ+, cogeneration fuel costs that are low when compared to electricity rates and a thermal demand closely matching the electrical demand. Retrofitting a boiler with cogeneration technology is possible if the existing boiler is oversized and is producing excess steam. This excess steam could be used to create power, heating, coolth or a combination of all.

- Tri-generation is an extension of co-generation. It involves simultaneously producing combined heating, coolth and power. Tri-generation is achieved by using the waste heat available to drive an absorption chiller as well as a power generator. The technology can be put to good use in the red meat processing industry due to the requirement for steam, refrigeration and electricity at red meat processing facilities.

With any of these three options, the following questions should be addressed at the planning stage of a project:

1. Is it technically feasible?
2. Is it economically viable?
3. Can strategies be developed for overcoming barriers to implementation?

This literature review gives an overview of the options as well as some general examples for reference purposes. It is important to note that the information offered here is general and not site specific – each red meat processing facility is unique in terms of its steam, power and refrigeration needs. As such, individual feasibility studies are required to determine the appropriate option for an individual plant.

Individual plant studies will be the subject of In-Situ boiler review report in 2014.

2.0 Introduction

The scope of this literature review is to document the published research relating to steam generation in meat processing facilities, produced by boilers of a number of different varieties. It is generally accepted that boilers are able to perform one of two roles; steam production and hot water production [1]. Both of these have their uses in the red meat processing industry. Steam is used in the rendering process and can be used to drive other equipment such as turbines and absorption coolers, while also delivering hot water for hygiene and other process needs.

Hot water boilers are not discussed in detail in this paper, as the focus for this review is on steam production, especially the ability to harness excess steam or produce steam in a more efficient way.

Steam is generated through the heating of hot water to boiling point. Boiler fuels can include coal, electricity, woodchips, biofuels, and natural gas/LPG.

Within meat processing facilities the demand for energy is high, while in recent times gas and electricity prices are rising rapidly due to a wide range of economic and social factors. Thus many meat processing facilities are seeking ways to reduce their gross input energy by rectifying areas of inefficient energy use, the prime candidates being steam production and refrigeration, for economic and environmental reasons.

Improvements in steam production can be made in a number of different ways:

- By looking at the fuel used in the boiler. The more traditional fuels, such as coal, could be replaced with alternate fuels like natural or biogas.
- Moving to newer and more complex options like co and tri-generation, or to harness excess boiler steam using a steam turbine.

This document is the first stage of an AMPC and MLA research project, with the next stages reviewing actual site options at four major meat processing facilities.

2.1 Steam & Heat Recovery Options

There are two methods for improving the steam/heat recovery efficiencies of boilers. These are:

- Retrofit/upgrade of existing infrastructure, or
- Removal and replacement of existing infrastructure.

There are a number of different methods for maximising the energy yield from existing boiler infrastructure:

- Addition of a turbine after the boiler to harness any excess steam, transforming it into electricity for use elsewhere at the facility, or exporting to the local power grid.

- Harness the exhaust gasses from a generator to produce additional steam, then using this steam to drive processes throughout the facility, including the boiler.

Both of these methods are forms of adapting existing systems into a co-generation plant.

The removal and replacement of existing infrastructure is not always a possibility as there are cost, productivity and availability of fuel source constraints to consider. The remaining life of the current boiler, the difference in efficiency between new and retrofitted systems, and technical challenges with integration all need to be considered when choosing whether to retrofit the existing infrastructure, or replace it with a new system.

If the current infrastructure allows for the addition of a heat recovery system, then this is most likely to be the best economic option in terms of capital cost and derived financial returns. However if that is not the case, then a replacement system could be a viable option depending on the final capital costs and returns.

The choice of thermodynamic cycle also affects the overall functionality and operation of the system. The factors to consider in choosing an appropriate thermodynamic cycle are outlined in Table 1 [2].

(Note: A description of each of the thermodynamic cycles, including a definition of the terms, are included in Section 4.6.1.).

Table 3: Factors to consider in choosing an appropriate thermodynamic cycle [2]

THERMODYNAMIC CYCLE	NEW INSTALLATIONS	EXISTING INSTALLATIONS
Topping	New ICI boiler or fired HRSG installations that produce high-pressure steam are ideally suited for integration into a steam turbine topping-cycle CHP system.	Existing ICI boiler and HRSG installations that use pressure-reducing valves are ideal candidates for integration into a steam turbine topping-cycle CHP system.
	New ICI boiler or fired HRSG installations that can be used to recover heat from gas turbines, micro turbines, reciprocating engines, or fuel cells are candidates for use in topping-cycle CHP systems.	Existing ICI boiler and HRSG installations that need to produce additional steam or hot water, should consider supplementing existing capacity with either a gas turbine, micro turbine, reciprocating engine, or fuel cell topping-cycle system.
		Installations with existing ICI boilers or fired HRSGs that can be modified to recover heat from gas turbines, micro turbines, reciprocating engines, or fuel cells are candidates for integration into CHP topping-cycle systems.
Bottoming	If a new installation includes an independent heat source such as a furnace or kiln, consider integrating the heat source into a steam turbine bottoming-cycle CHP system. Heat recovered from the process can be used to produce steam, increase the	If the installation has an independent heat source such as a furnace or kiln that produces high-temperature exhaust gases and it is possible to recover heat from the exhaust gas stream in a heat-recovery device such as an unfired HRSG or heat exchanger, consider integrating the heat

	temperature of feedwater, or preheat combustion air.	source into a stream turbine bottoming-cycle CHP systems.
Combined	New ICI boiler or fired HRSG installations that are capable of using the mechanical and thermal energy generated by gas turbines, micro turbines, or reciprocating engines are candidates for use in combined-cycle CHP systems.	Existing ICI boiler or fired HRSG installations that are capable of using the mechanical and thermal energy generated by gas turbines, micro turbines, or reciprocating engines are candidates for integration into combined-cycle CHP systems.
Trigeneration	If a combined-cycle system is a viable option and a cooling effect is required, consider a trigeneration CHP system.	If a combined-cycle system is a viable option and a cooling effect is required, consider a trigeneration CHP system.

Note: ICI stands for industrial/commercial/institutional and HRSG stands for heat-recovery steam generator [2].

In the red meat processing industry, there are two main modes of operating a co-generation system:

- Base load operation. This allows for the base electrical or thermal load to be supplied onsite with any extra energy required being supplied by the grid. Doing so would reduce the facilities demand for electricity from the grid, thus reducing the demand charge and the total electricity bought from the grid.

- Peak shaving operation. This helps to lower the average price of grid power for the facility and could therefore provide good economic returns.

When choosing between the two options the difference between the peak and standard electricity rates as well as the capacity/demand charge need to be considered, as both can be affected and contribute to overall savings and therefore project viability.

2.2 Operational Scale Requirements

In general, the larger the facility, the broader the scope for cogeneration becomes.

The minimum yearly thermal load for cogeneration to be technically viable is commonly noted at 2000 GJ/1894 MMBtu *(refer to explanations in Section 4.5.)* This corresponds to about 556 MWh. Assuming that the facility is operating 24/5 for 48 weeks a year (5,760 hours a year) then the average load will be a very small 63kW, and as such only very simplistic heat transfer devices could be supported by such a small electrical demand.

In Australia a facility would need to operate at an electrical load of 500kW or above, for any form of complex co-generation to become viable. This would be the equivalent of a boning operation, while a full scale meatworks is likely to run with an electrical demand exceeding 1MW.

At suitable scale, co-generation systems can result in energy savings of up to 47% when compared to standard power/boiler configurations. With ongoing rising in energy costs likely over the coming decade, the attractiveness of co-generation where steam is a key process requirement is rapidly building.

2.3 Site Data Needed

To enable a detailed investigation of co and tri-generation, certain information is required about specific sites. This includes [3]:

- 12 months coal, biomass, electricity and gas consumption and tariff data
- Thermal load profiles and boiler fuel information over a 12 month period
- Any planned changes to current consumption, such as site expansion
- Previously identified and implemented energy efficiency measures
- Details of existing utility systems, such as a site electrical system distribution diagram along with knowledge of local electricity network capacity limitations
- Plan drawing showing location of utilities and probable location of cogeneration plant
- An electricity network load flow study to determine how the cogeneration unit will impact on network performance, and
- Availability of fuel, including biogas or other renewable fuels.

Each of these factors contributes to the commercial viability of any heat recovery or cogeneration system under consideration.

3.0 Steam Boilers

3.1 Fuel Types

Steam boilers have traditionally been operated with fuels including coal, gas, oil and diesel, methane (captured biogas from anaerobic digestion systems) and biomass (paunch, woodchip). Steam generation can occur in two primary fashions, either as a direct product from the boiler or as a by-product from electricity generation.

In the meat processing industry, steam is used by plants that render by-products. Steam is generated in boilers fuelled by coal, fuel oil, natural gas or LPG. Black overburden coal is the most commonly used fuel in Northern Australia (as it is effectively a waste product that is locally produced and traditionally has been cheap), while in the Southern States natural gas has been readily available from the Victorian and NSW piped network.

The typical fuel costs for energy and steam production in the red meat industry is shown in Table 2 and Table 3 [4]. Black overburden coal is considerably cheaper than other options.

This table assumes a dedicated steam boiler with no co-generation functionality, and it is in prime working order and is right-sized to the plant in question.

Further there is no “environmental” aspect to the direct financial analysis, in terms of social responsibility, market driven demands or prices on carbon emissions.

Table 4: Typical costs for primary energy sources [5] [6] [7]

FUEL	CALORIFIC VALUE	$/ QUANTITY	$/GJ
Coal	27.0 MJ/kg	$98.57/t	$3.65
Natural Gas	39.3 MJ/m^3	$0.2/m^3	$5.09
Electricity	3.6 MJ/kWh	$0.08/kWh	$22.22
Diesel Oil	38.6 GJ/kL	$927.24/kL	$24.02

Table 5: Typical fuel costs for steam production [5] [6] [7]

	COAL BOILER	NATURAL GAS BOILER	DIESEL OIL BOILER
	(85% efficiency)	(95% efficiency)	(90% efficiency)
Energy content of steam	2.8 GJ/t steam	2.8 GJ/t steam	2.8 GJ/t steam
Fuel energy input	3.3 GJ/t steam	2.9 GJ/t steam	3.1 GJ/t steam
Quantity of fuel	122 kg coal/t steam	74 m^{3}gas/t steam	80 L oil/t steam
Cost	$12.05/t steam	$14.76/t steam	$74.18/t steam

As a comparison tool, it is also advantageous to review studies related to power generation to draw conclusions on the relative efficiency and emissions intensity of various fuel sources, given many of the same fuels are used in power plants on mass scale as they are in meat processing boilers on a smaller scale.

In 2013 the Australian Governement published the National Greenhouse Accounts Factors report. This report contains the emissions factors of various different fuel sources. It was designed to be used by companies and individuals to estimate greenhouse gas emissions. Table 4 shows the emissions factors of the different fuels discussed in this section.

Table 6: Boiler Fuels and Emission Factors [5]

FUEL COMBUSTED	EMISSION FACTOR (kg CO_2-e/GJ)		
	CO2	CH4	N2O
Brown coal	92.7	0.01	0.4
Biomass	0	0.6	1.2
Natural gas	51.2	0.1	0.03
Diesel oil	69.2	0.1	0.2
Black coal	88.2	0.03	0.2

While coal may be cheaper as a fuel source, it is clearly the most exposed in terms of emissions compared with gas or waste-to-biomass boilers.

3.1.1 Coal

Coal has a high emissions factor and as such placed larger meat works facilities within the scope of the Carbon Pricing Mechanism (CPM)[1].

In addition to the CPM, there are significant monitoring and improvement legislation requirements under the Energy Efficiency Obligation (EEO) act and the National Greenhouse and Energy Reporting (NGER) act that larger meatworks are obliged to document and make attempts to improve upon.

Australia contains 9% of worlds total coal reserves placing it within the top six coal producing countries [8]. Hence coal is a major mining industry within Australia and is a comparatively cheap fuel source, and especially in Queensland and NSW black coal is readily available. Victoria's coal reserves are mainly brown coal in the LaTrobe Valley, which is not suited to use in boilers due to its moisture content. Victoria has also has open and cheap access to Natural Gas from Bass Strait with a major gas network state-wide, thus coal is not as predominant in Victoria as it is in the Northern States.

The price and availability of black coal in the Northern States makes it an ideal boiler feed. Australian thermal coal was at an average price of AU$94.23 [9] throughout November 2013. Below is a table from the most recent "Energy in Australia" report, published by BREE in May 2013. The change in coal prices over the past 5 years [10] is shown in Table 4.

Table 7: Coal prices [10]

	2008	2009	2010	2011	2012
Metallurgical coal, hard [b]					

[1] At the time of writing this document the CPM was still legislated and applied, however the recently installed Abbott Government has a publicly stated policy to repeal the Carbon Tax but does not have the Senate control to implement the change until mid-2014.

US$/t	300.00	128.00	214.75	291.25	192.50 **es**
A$/t	377.68	150.07	227.73	279.03	186.67
Real A$/t	417.80	162.87	240.05	287.12	188.02
Metallurgical coal, other [c]					
US$/t	240.00	80.00	191.94	179.28	131.25 **es**
A$/t	302.14	93.79	203.54	171.76	127.28
Real A$/t	334.24	101.79	214.55	176.74	128.20
Thermal coal [d]					
US$/t	125.00	70.35	98.00	129.85	115.00
A$/t	157.37	82.48	103.92	124.40	111.52
Real A$/t	174.08	89.51	109.55	128.01	112.33

*Notes: **a**-Japanese fiscal year beginning 1 April. Prices are fob Australia basis; real prices are in 2010 Australian dollar terms. **b**-For example, Goonyella export coal. **c**-Non-hard coking coal price based on Australian/ Japanese contract settlements. **d**-For thermal coal with a calorific value of 6700 kcal/kg (gross air dried).**e**-Average of first three quarters of year.**s**-BREE estimate*
SOURCES: BREE, IEA, Coal Information.

Emissions produced by coal fired boilers are dependent on the composition and quality of the coal. Coal is composed predominately of carbon, hydrogen and oxygen; nitrogen and sulphur may also be present. The resulting emissions may include greenhouse gases CO_x, NO_x and SO_x. CO_2 (carbon dioxide) is the dominant gas emitted [11]. The average emissions factor for coal in industrial use (as distinct from that used solely for power generation) is 88.2 kg CO_2-e/ GJ [5].

3.1.2 Diesel/Oil

Diesel and oil boilers are generally utilised in remote areas where the cost of transporting alternative fuel sources outweighs the cost of diesel/oil.

Crude oil, diesel and petrol are different products and are bought or sold in their own markets. Each market is typically regionally based and there are linkages and transactions between regional markets. Diesel prices in regional markets reflect the supply and demand balance in each market. Thus diesel prices (like other commodity prices) are determined by market forces, not production costs. The Australian Institute of Petroleum shows the average retail diesel price varied between 142 cent/Litre and 151 cent /litre from Sep 2013 to Dec 2013 [12].

The emissions factor for diesel is 69.2 kg CO_2-e/ GJ and the emissions factor for fuel oil is 72.9 kg CO_2-e/ GJ [5].

3.1.3 Gas Fuels

Gas fuels are operationally superior to other traditional fuels, such as diesel and coal, because they require the least amount of handling and are used in the simplest and most maintenance-free burner systems. Gas is delivered "on tap" via a distribution network in most urban areas, thus is suited for areas with a high population or industrial density [1].

The following is a list of the types of gaseous fuel [1]:

- Fuels found in nature:
  - Natural gas
  - Methane from coal mines (Waste Coal Mine Gas).
- Fuel gases made from solid fuel:
  - Gases derived from coal
  - Gases derived from waste and biomass
  - From other industrial processes (blast furnace gas).
- Gases made from petroleum:
  - Liquefied Petroleum gas (LPG)
  - Refinery gases
  - Gases from oil gasification.
- Gases from a fermentation process.

3.1.4 Natural Gas

Methane (Propylene and Butylene) is the main constituent of natural gas and accounts for about 95% of the total volume [1]. Natural gas and LNG are limited as a fuel source by their availability via shipping, road transport or pipelines. Natural gas is a highly demanded commodity with limited/controlled availability in pipelines outside of capital cities. Melbourne especially has an extensive gas pipeline network, a legacy of the 1960's-1980's State Government policy to develop and utilise the Bass Strait gas fields via the Government-owned business Gas & Fuel Corporation.

Distribution and currently accessible reserves are therefore limiting factors to natural gas supply. The price of natural gas over the past 5 years [10] is shown in Table 5.

Table 8: Australia gas prices [10]

			2007/08	2008/09	2009/10	2010/11	2011/12
Natural Gas	Nominal	$A/GJ	3.77	3.32	2.03	2.42	3.42
	Real	$A/GJ	4.12	3.52	2.10	2.43	3.42
Natural Gas	Nominal	$A/GJ	2.94	3.77	3.71	4.11	4.20
	Real	$A/GJ	3.21	3.99	3.84	4.12	4.20
LNG	Real	$A/t	465.66	690.00	449.45	522.98	623.64
		$A/GJ	8.56	12.68	8.26	9.61	11.46

SOURCE: BREE 2012, Resources and Energy Statistics; AEMO 2012; WA Department of Mines and Petroleum 2012.

Natural gas is a high calorific value fuel, 39.3 MJ/m^3 [5], requiring no storage facilities. It mixes with air readily and does not produce smoke or soot. The emissions factor for natural gas is 51.2 kg CO_2-e/ GJ [5].

3.1.5 LPG

LPG is a predominant mixture of propane and Butane with a small percentage of unsaturates (Propylene and Butylene). LPG is stored and transported as liquid under pressure for convenience and ease of handling. Liquid LPG evaporates to produce about 250 times its volume of gas [1]. The ACCC published the average retail price of LPG in Australia's five largest capital cities during 2010–11 as 62.6 cents per litre (cpl). Below is a table showing the historical prices for LPG in comparison to the other mentioned fuels.

Table 9: Historical Fuel Prices (2010-2014) [6] [7] [13]

	COAL ($/TONNE)	DIESEL/OIL ($/GALLON)	NATURAL GAS ($/MMBTU)	LPG ($/TONNE)
2010	115.34	2.39	4.80	799
2011	126.23	2.92	3.87	805
2012	99.57	3.00	2.66	883
2013	93.49	3.12	3.85	877
2014	98.57	3.51	5.52	1,125

LPG is a popular cooking, heating and transport fuel around Australia, with major trucking and shipping networks in place, and the market is dominated by a small number of large producers.

Where pipeline natural gas is not available, many major facilities have onsite LPG tank storage, including a number of large abattoirs.

3.1.6 Methane

Methane boilers utilise the gases produced by waste product in the abattoir's anaerobic holding ponds, or through solids digesters.

For Covered Anaerobic Lagoons (CALs) the gas is captured off the anaerobic lagoons generally via relatively low-tech concepts like a plastic blanket with vacuum extraction of the gas, which is then burnt or compressed and stored for later use in boiler combustion.

Typically, the composition of raw biogas from anaerobic digestion [14] is:

- Methane CH4 50%-80%
- Carbon dioxide CO2 20%-50%
- Water Vapour H2O Saturated 2-5% (mass)
- Nitrogen N2* 1-4%
- Oxygen O2* < 1%
- Hydrogen sulphide H2S 50-5000 ppm
- Ammonia NH3 0-300 ppm
- Trace gases Siloxanes and halogenated hydrocarbons in very low concentrations
- Non-gaseous Particulate and oil in low concentrations

*Only present if air is injected into the digester for H_2S reduction

Recovered biogas tends to be "unclean" due to the presence of CO_2 and especially the toxic and corrosive H_2S. [15] Thus it is extremely difficult to transport and store effectively, especially where it is produced in commercial quantities. Even for use in a boiler, biogas can be damaging and requires a specialist burner system.

Thus when biogas is stored or combusted in a boiler or engine, it may require scrubbing to remove impurities including H_2S and NH_3. This can be done via a number of scrubbing technologies, including a biological trickling filter, a biological scrubber, absorption on iron containing media, and water scrubbing [16].

Each of the methods of scrubbing has relative merits depending on the circumstances applying at each site, however without removing the N_2S and NH_3 use of locally produced biogas would likely cause equipment damage and the release of unacceptable quantities of toxic fumes to atmosphere.

Where methane from waste biomass is recovered and flared or combusted for energy, the CO_2 emitted is not counted as a greenhouse gas emission, but regarded as part of the natural carbon cycle. The total amount of methane recovered is therefore regarded as saved (not emitted) so long as it does not enter the atmosphere as methane [5].

3.1.7 Biomass

Biomass as a fuel for boilers consists mainly of wood or waste wood products such as chips or sawdust. It can also include sugar bagasse, paunch, nut shells such as almonds or macadamias, or olive skins/pitts or grape skins, all of which have calorific content.

Biomass generally is a low energy density fuel - less energy from a greater quantity - so a lot of storage space is needed for a biomass boiler [5]. Table 6 shows a comparision between the calorific values of biomass and the other fuels discussed in this section. From this table it can be seen that biomass has a lower calorific value than nearly all the other fuel types.

Table 20: A comparison between the calorific values of biomass and other fuels

FUEL	CALORIFIC VALUE
Black Coal	27.0 GJ/t
Brown Coal	10.2 GJ/t
Natural Gas	39.3 MJ/m^3
Diesel Oil	38.6 GJ/kL
Fuel Oil	39.7 GJ/kL
Biomass	12.2 GJ/t

This is not a common steam generation solution in the Australian meat industry, however it is common in industries that produce their own biomass, such as sugar and nut producers.

Biomass boilers tend to utilise the organic by-products of other nearby ventures. This type of boiler is a feasible option if the facilities are near sawmills or nut producers and are able to access waste wood or shells, otherwise it can prove to be expensive [5] and fuel sources can become unreliable or seasonal. Even under storage, many of the fuel sources degenerate quickly after production, resulting in the fuel becoming unusable.

Emissions of CO_2 generated from biomass sources are considered to be from waste management and therefore do not need to be estimated under current regulations. If biomass has to be transported considerable distances then it's no longer zero carbon [5].

Where waste material is diverted from landfill to recycling or to energy use, the reporting organisation will have fewer emissions attributed to its activities because less waste is going to landfill [5].

4.0 Co-Generation

4.1 Concept Theory

Co-generation or combined heat and power (CHP) is the sequential production of two forms of useful energy, usually electrical and thermal, from a single fuel source [2].

Cogeneration systems have an economic and environmental advantage of an overall system efficiency increase over direct combustion for thermal energy production. Their efficiency can be as high as 80% [3] because the input energy is transferred into both heat and power. At a conventional power station that is producing only power, the conversion efficiency is only around 30-40% [3]. The remaining 60-70% is lost as un-recovered heat.

4.2 Commercial Viability

The following three areas need to be addressed in order to determine the viability of a cogeneration project [2]:

1. Is cogeneration technically viable?
2. Is cogeneration economically feasible?
3. Can strategies be developed for overcoming barriers to implementation?

The following factors auger well for a cogeneration project [2] [3]:

- High electricity prices (at least three times higher than that of alternate fuel sources)
- High electricity demand and peak usage charges
- Operations take place during peak electricity tariff periods
- Average electricity load is greater than 500kW
- Annual thermal fuel consumption greater than 2,000 GJ/1894 MMBtu so that a good heat to power ratio is available
- Ratio of average electric load to peak load exceeding 0.7, indicating steady demand for heat and power throughout the year

- Long annual operating hours (minimum of 4,380hrs/annum) providing continuous system operation and high equipment utilisation rates
- Thermal demand profile closely matching electric load
- Blackouts or brownouts in the electricity supply network are an ongoing and regular issue that can be partially or fully resolved by the proposed cogeneration project
- Emergency electricity back up is being considered
- A boiler is being replaced, and
- Grants or financial support are available.

There are also some factors that can enhance the potential of successfully applying cogeneration technology at new or existing boiler installations [2]. These include:

- Cogeneration systems are sized to satisfy the thermal needs of the process. In some, but not all cases, oversized systems are generally more costly and less efficient
- Unless inexpensive solid, liquid, or gaseous fuels are available, natural gas is the preferred fuel for most new cogeneration applications because of its relatively low cost, low emissions and generally wide availability
- Heat load and power demand occur simultaneously. These demands should be present for at least 4,380 h/year. However there are applications where cogeneration systems could be cost effective with fewer hours. The most cost-effective applications are those that operate continuously all year round (8,760 h/year)
- Power-to-heat ratio for the plant does not fluctuate more than 10%
- Cogeneration technology is commensurate with the required power-to-heat ratio of the plant
- The cogeneration system needs to have high availability.

4.3 New versus Retrofit

There are a number of factors to consider when choosing whether to retrofit an old boiler with cogen/trigen technology, or invest in a new system:

- Lifetime of the existing boiler
- Compatibility with existing equipment and future expansions - can the system be upgraded in stages?
- The financial savings comparison between retrofit and new
- Potential technical challenges associated with retrofit.

A retrofit may save money in the short term with lower capital costs, but may not be a good investment in the long term. This can be due to the efficiency of a new system being higher (thus speeding up the payback period), more specialised and complex design and maintenance is required for retrofit systems, and the potential for the existing boiler requiring replacement in the short term.

A case-by-case analysis is required for each site to determine the format of any new initiative.

4.4 Benefits

Due to the ability to produce electricity in the range of a few kilowatts (kW) to a few hundred megawatts (MW), cogeneration systems it can be sized to meet the exact demands of an abattoir [3].

The primary benefits of co-generation can include [3]:

- Reduced electricity and fuel costs resulting from increased efficiency
- Increased reliability and quality of electricity supply
- Reduction of greenhouse gas emissions and particulate matter
- Protection against electricity price fluctuations
- Increased employment and employment security, particularly in rural and regional areas, and
- It can utilise renewable fuels such as biomass or methane.

4.5 Technical Overview

4.5.1 Thermodynamic Cycles

A thermodynamic cycle consists of a linked sequence of thermodynamic processes that involve the transfer of heat and work into and out of a system. In the context a cogeneration system this refers to the configuration or placement of the different components in the system in relation to each other.

There are three cycles for steam production in the red meat processing industry; the bottoming cycle, the topping cycle, and the combined cycle. The bottoming cycle involves the utilisation of the existing steam boiler with the addition of a turbine [2]. The arrangement of this system is shown in Figure 1:

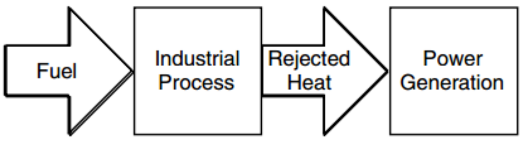

Figure 1 Bottoming-Cycle schematic [2]

This is only useful if significant excess steam is produced. This excess steam can be used to run the turbine creating electricity which can be utilised elsewhere in the abattoir or exported to the power grid.

The topping cycle involves the installation of a generator where the by-product of creating electricity is steam [2]. The arrangement of this system is shown in Figure 2.

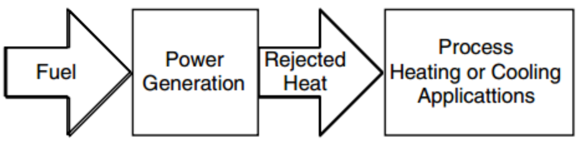

Figure 2 Topping-cycle schematic [2]

The viability of this cycle is dependent on the quantity of steam required and the size of the generator that would be required to produce the steam.

Combined-cycle CHP systems area combination of a bottoming cycle and a topping cycle that are interconnected and operating at different temperatures [2]. The topping cycle is operated at a higher temperature and rejects heat that is recovered and used in the lower temperature bottoming cycle. This produces additional power and improves the overall system efficiency [2].

These types of CHP systems are typically range in size from 22 MW up to around 400 MW [2]. The also often require less floor space than separate combustion and steam turbines with comparable electricity output [2]. These reduced space requirements can help when trying to integrate CHP technology into existing boiler installations [2].

4.5.2 Engine Types

There are a three main types of prime movers available for cogeneration; steam turbines, gas turbines, and reciprocating engines. Steam turbines are typically less efficient than gas turbines due to the inherent fuel properties and the need to convert fuel to steam prior to use in the turbine. Steam turbines are typically coal or solid fuel fired whereas gas turbines run on gaseous fuels and have a much higher fuel conversion efficiency into electricity.

Figure 3: Tablelands Sugar Mill Bagasse-fired Steam Generator

However steam turbines have the advantage of being able to use cheap solid fuels such as coal and biomass [3].

They are widely used in the sugar industry where bagasse, a waste product from cane processing, is used as the fuel source [3].

The boiler is used to generate the steam which is fed in to steam turbines to generate electricity or steam [2]. The waste steam from the steam turbine is then used for process heating. Steam turbine powered cogeneration systems can be up to 85% efficient. However they typically produce a higher proportion of heat than electricity [2].

Gas turbines are suitable for applications where high-pressure steam is required (1,200kPa or more). They can be sized from 1MW to over 200MW. The capital costs for a gas turbine cogeneration system are 50-70% lower than an equivalent steam turbine [2].

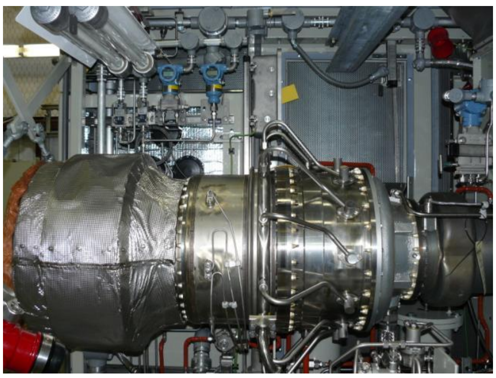

Figure 4 Gas Turbine & heat recovery generator at Devro, Bathurst

Reciprocating engines can be operated as cogeneration systems by recovering the heat from the engine exhaust and jacket coolant. Approximately 70-80% of fuel energy input is converted to heat that can be recovered to produce hot water up to around 100ºC, or low pressure steam.

They are ideal where high pressure steam is not required. They are also generally smaller in size, being less than 3MW.

As pressure and volume are inversely proportional to temperature, the more heat produced the lower the temperature it will be. So an increase in either volume or pressure will decrease temperature, thus steam plants with a cogenerator will only produce half as much heat as electricity. However hot water plants with a cogenerator can produce up to 20% more heat than electricity. They can run on a range of fuels from natural gas through to heavy fuel oil and even combinations of fuels [2].

Out of these three methods the most common in the meat industry is reciprocating engines with heat recovery [3].

4.5.3 System Sizing

The sizing of a cogeneration system depends on the thermal and electrical energy load at a site. The system can be designed to meet all or part of either one. It is important to know if the thermal and electrical energy demands will occur at the same time, as this will help determine if thermal energy storage is required.

In a typical meat processing plant including onsite rendering, the thermal energy demand is typically at least twice that of the electrical energy demand. If all the energy demands were to be met then the plant would be sized to meet the thermal energy demand. This could result in excess electricity generation that would be available for export [3].

4.5.4 Fuels

Since waste heat co-generation plants still use steam boilers as their central component, the different fuels, discussed in Section 3.1, can be used in co-generation also.

Natural gas is the most commonly used fuel in turbine or reciprocating engine co-generation plants. The last decade has seen significant advances in lean burn gas engines. They have substantially lower emissions than the older engines. In Australia there are natural gas cogeneration plants ranging in size from 200kW up to more than 200MW, with in excess of 10,000MW of currently installed capacity. Natural gas may be blended with biogas, with the biogas produced from the waste product of the facility or one nearby. However it is important to make sure that the main engine/turbine is designed with the ability to use the blended fuel [3].

Diesel is a common type of liquid fuel used in cogeneration plants. However as previously discussed, due to its higher costs it is generally only used in remote applications where natural gas is not available and neither is the electricity grid. It is suitable for use in reciprocating engines [3].

Other than cost, the main difference between the fuels is the associated emission levels. This can be seen in Table 6 comparing diesel and natural gas [17].

Table 11: Emission Comparison: Diesel and Natural Gas [17]

FUEL	DIESEL	NATURAL GAS
Shaft output	9200kW	9000kW
Shaft efficiency	45.3%	46.5%

FUEL	DIESEL	NATURAL GAS
Nitrogen oxides (NO_x)	14.8 g/kWh	1.2g/kWh
Carbon monoxide (CO)	0.9 g/kWh	2.1 g/kWh
Hydrocarbons (THC)	0.7 g/kWh	6.5 g/kWh
Particulates	0.5 g/kWh	0.03 g/kWh
Carbon dioxide (CO_2)	650 kWh	435 kWh

4.5.5 Operating Modes

It is necessary to consider how and when the cogeneration system will operate. There are a few different modes of operation that can be used to achieve a particular strategic objective; isolated design and operation, base-load design and operation, load-tracking design and operation, peak shaving, and economically dispatched.

In the Isolated Design and Operation mode, the cogeneration system is sized to meet the site peak electric load with reserve allowance for short-term transients. This allows the system to run disconnected from the grid meaning that no electricity purchases will need to be made from the utility [2]. However, in the event of a system failure this could slow or stop production if no measures are put in place to account for this, since the grid is not available as a backup. Also this mode will run at full capacity the entire time, potentially wasting fuel when supply exceeds demand.

In the Base-Loaded Design and Operation mode, the cogeneration system is interconnected to the electrical grid and is sized to meet the site's base-load requirements. In this mode, no redundant capacity is required and only supplemental power in excess of the base load is purchased from the electric utility [2].

In the Load-Tracking Design and Operation mode, the cogeneration system is interconnected to the electrical grid and sized to track either the site's thermal or electric load. By doing so, both electric and thermal approaches can be taken to supply the site's peak requirements. However this could mean that supplemental power purchases, heat rejection, or supplemental thermal energy are required [2].

In the Peak Shaving mode, the cogeneration system is designed to satisfy the site's peak power requirements either by operating during the site's peak demand period(s) or during the utility's peak demand period(s). This means that the purchase of more expensive on-peak power is avoided and thus the average price of power is decreased [2].

In the Economically Dispatched mode, the cogeneration system is operated using an approach based on a number of different factors; the value of purchased power and the boiler fuel costs relative to the cogeneration system fuel, maintenance costs and the ability to use recoverable heat. By operating in this mode it is possible to use microprocessor control systems to perform real-time calculations of operating costs and cost of savings as a basis for making decisions. In addition, if the cogeneration system has electric capacity that exceeds the energy needs of the facility, this excess capacity can be sold to the wholesale market when prices are favourable [2].

Any of these different modes could be used at an abattoir; however some are more commercially viable than others.

The Base-Loaded Design and Operation mode would require the least complex technical design and would also produce reasonable economic savings. It also meets the intrinsic needs of an abattoir – steam and power availability – thus is the most likely design concept.

The Peak Shaving mode would help to lower the average price of power for the facility, however this would require a slightly higher level of technical design and would face some challenges such as switching control ability to power on and off at the right times. Additionally, this option could require new steam plant.

There is also the possibility of designing the plant as a standby plant to be used in emergency situations to help ensure the reliable supply of energy [3]. Cogeneration provides this functionality normally but can also be specifically tailored to it.

The other modes are rather complex and thus less viable for implementation in a meat processing industry.

4.6 Economic Overview

4.6.1 Economic Feasibility

For a cogeneration system to be considered economically feasible then its operating costs to deliver steam and power must be lower than the cost of operating a traditional boiler and acquiring power from the National Grid. Additionally, there must be an investment case that delivers strong returns over the status-quo – potentially triggered by legislative need or a major plant replacement imperative.

There may also be a case to oversize the electricity capacity of a co-generator to export power to the grid to create a revenue stream. The criteria for assessing the economic feasibility of cogeneration is summarised in Figure 5.

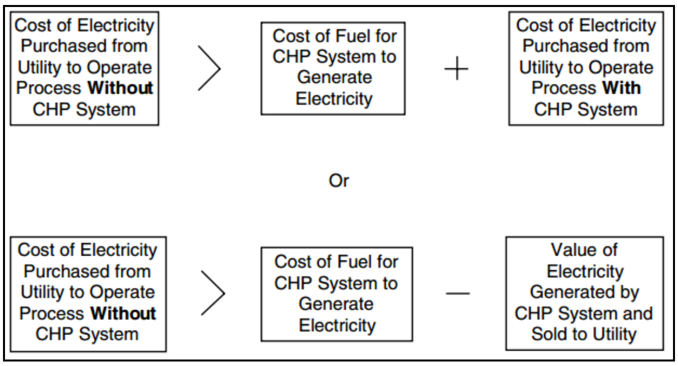

Figure 5 Criteria for assessing economic feasibility of cogeneration technology [2]

4.6.2 Capital Costs

CSIRO's report [18] on the Maine's Power Project documented the capital costs for a fully installed and commissioned natural gas cogeneration unit to be between $1,500 and $2,200 per kilowatt (electric). This can be higher for smaller units with units less than 800kW likely to be $2,200 per kW or more.

The actual capital cost will vary depending on the following [3]:

- The plant size – generally costs increase with size
- type of reciprocating engine or gas turbine – gas turbines tend to be more expensive at smaller sizes but produce higher grade heat
- Fuel handling and delivery systems for solid fuel fired systems
- Required civil engineering works for project
- Water treatment costs (if not already integrated into the facility) for cogeneration system
- Connection costs to site, such as steam and water piping
- Electrical interconnection and safety works at the plant, such as switch gear
- Foreign exchange rates, if parts are sourced from overseas
- Connection charge, if grid connected, to export power to the local distribution network – voltage control, incident stability, protection issues, power quality, etc, and
- Any demand incentive schemes such as the federal government Emissions Reduction Fund that is set for release early 2014.

If a biofuel is being used in the system then the capital costs are generally expected to be higher. The greater capital is due to costs associated with the additional equipment such as the bio-digester to process the bio-fuel from produce waste, as well as integration with the existing equipment. This is offset by the lower fuel cost.

4.6.3 Operation and Maintenance Costs

The main operational cost for cogeneration plant is the cost of fuel supply. An example of a natural gas cogeneration plant is demonstrated by the following:

- Cost for natural gas $3.42/GJ [10]. Assuming 36% electrical efficiency, this is about $120/MWh or 12c per kWh.

The operational and maintenance costs vary depending on the system. The costs can include [2]:

- Gas engine – major overhauls every 40,000 hours to 64,000, costing $300-400K + 3-4 weeks downtime. It may be cheaper to replace the engine. Operation & maintenance ranges from $15-20 per MWh (1.5-2 c/kWh)
- Gas turbines – 4-6% of the capital cost for a small plant, less for plants above 50MW i.e. $10-20 per MWh (1-2c/kWh), major overhauls every 12,000-50,000 hours
- Steam turbines - $2/MWh (0.2 c/kWh), major overhauls every 50,000+ hours, extra costs for fuel handling and boiler operation.

4.6.4 Simple Payback Period

There are a number of different investment assessment tools in use including Internal Rate of Return (IRR) and Net Present Value (NPV), however the complex nature of these tools means that they have inputs that are company specific, such as cost of capital, CPI forward views, discount rates and the like. As such a broad brush Simple Payback Period can be used as a typical "is it worth investigating" judgement tool.

A quick method for determining the potential feasibility of natural gas fired system is by looking at the price differential between gas and electricity.

If the price of electricity is three times that of gas then it is usually worth investigating further, taking into account capital returns. Below is an example of how this works.

Gas cost $3.42/GJ = 1.23c/kWh
At engine efficiency of 32% = 1.23/32% which = $3.84c/ kWh
Delivered electricity cost = $14c/kWh
Ratio (electricity cost to gas cost) = 3.7:1
=> Potentially a viable project exists
=> With "free" steam it definitely will

Another fast and simple way to consider economic feasibility is to do a simple payback calculation that takes into account the forecast electricity saving achieved by the project.

For example:

- 2MW gas turbine cogeneration unit
- This unit produces 3MW of steam
- System cost is $4.4 million
- the site pays an average of $0.14 per kWh
- electrical efficiency is 32%
- boiler efficiency is 80%, and
- gas cost is $3.42 per GJ and 5,760 hours of operation per year (full 5 days a week for 48 weeks a year).

Simple payback period does not consider all costs and benefits of a project, however it can be used to indicate whether a project should enter into an early stage feasibility program.

Total installed capital costs are: 2,000kW x $2,200/kW

= $4.4 million

Annual electricity saving of: 2,000kW x 5,760h x $0.14

= $1,612,800

Annual boiler fuel saving of: [3 MW x 5,760h x 3.6 GJ/MWh X $3.42]/0.8

= $265,939

Generator operating costs of: [2MW x 5,760h x 3.6 GJ/MWh x $3.42]/0.32

= $443,232 (excluding maintenance costs)

Simple payback period of: just over 3 years

- 3 year Operational Cost = $1.33M
  Capital Cost = $4.4M
  Total cost over 3 years = $5.73M

- Three Year Saving in energy and fuel = $5.634M

5.0 Tri-Generation

5.1 Concept Theory

Tri-generation is an extension of the co-generation concept. Additional to producing heat/steam and electricity there is the production of coolth [2] for refrigeration.

Tri-generation works in the same manner as cogeneration except that a portion of the heat is passed through an absorption chiller refrigeration system to produce coolth. This can be in the form of simultaneous heating and cooling production, or staged heating and cooling production. Absorption refrigeration allows for the refrigeration cycle to be driven by waste heat where other types of refrigeration would use electricity [3].

There are two main types of absorption refrigeration systems; lithium bromide/water and water/ammonia. The first can produce temperatures above 0^{o}C, requires heat in the range of 60-150^{o}C and have fuel costs that are comparable to conventional chillers [18]. The second can produce temperatures down to -60^{o}C, requires heat in the range of 100-200^{o}C, is more expensive than the first and has fuel costs slightly higher at -10^{o}C, but nearly half at -20^{o}C [18]. This makes the second option better for facilities that require freezing and the first option better for facilities that only require refrigeration.

The meat industry could make good use of simultaneous production because abattoirs use the heat as steam for rendering or hot water production. The coolth produced can be used for refrigeration or cold water production. The electricity generated is used in various processes around the factory. All these types of energy are used simultaneously and allow for tri-generation to be utilised effectively. This results in the most efficient use of the input energy and returns three different types of usable energy.

5.2 Commercial Viability

When looking at a tri-generation system, the same three questions as for cogeneration systems should be asked:

5 Is tri-generation technically viable?

6 Is tri-generation economically feasible?

7 Can strategies be developed for overcoming barriers to implementation?

The main economic difference between co and tri-generation systems is the capital cost. The cost of tri-generation plant with absorption chiller tend to be higher, being $2,500 per kiloWatt or more [3].

An essential factor in determining the viability of a tri-generation project is the presence of large amounts of excess steam and the age of the existing boiler plant.

If the existing boiler is significantly oversized but not in need of replacement in the next 5-10 years, tri-generation could be a very attractive proposition.

However it is unlikely that a gas-fired new-build cogenerator could be economically sized to include an absorption chiller, unless a very attractive power export contract could be secured. Due to the extra thermal energy that's needed to efficiently operate the absorption chiller, the co-generation plant would need to be oversized, costing more in capital, and producing excessive electrical energy and wasted fuel, assuming the electrical energy isn't stored or sold back to the grid.

6.0 Project Reviews

Below are project reviews of different food processing facilities in Australia that have undertaken steam boiler alterations and improvements in recent years.

6.1 PR 1: Wodonga Rendering

Wodonga Rendering is located in Wodonga, northern Victoria and is capable of processing approximately 25,000 tonnes of meat products annually approximately 900,000 animals annually (State Government Victoria, 2013). Wodonga Rendering are in the process of constructing a $4.12 million tri-generation plant [21].

The tri-generation plant will be run off natural gas and will create electricity, heat and steam, all which will be utilised by the red meat processing facility [21]. It has been estimated that the utilisation of the natural gas tri-generation plant will reduce greenhouse gas emissions by 41% or approximately 11,900 tonnes [21]. The plant will be able to provide 2MW of three-phase 50 hertz electricity [21]. It is anticipated that this plant will reduce the plant's electricity requirement by approximately 73% [22].

This case study is an example of the implementation of tri-generation in a red meat processing facility to reduce electricity costs. The suitability of tri-generation such as that being constructed at Wodonga is dependent on electricity consumption and the cost of balancing production of all three items; electricity, heat and steam.

6.2 PR 2: Midfield Meats, Warrnambool

Midfield Meats is located in Warrnambool, southern Victoria and processes beef, lamb, veal, mutton and their by-products. In early 2009, Midfield meats constructed a 1.5 MWe natural gas fired co-generation plant [23].

The fully automated co-generation plant is natural gas fuelled and capable of meeting approximately 70 to 80% of Midfield Meats consumption requirements and almost all the hot water requirements with production of 1.7MW of thermal energy [24] [23]. It has been reported that the co-generation plant is responsible for almost halving the sites emissions (a reduction of 9,600 tonnes of CO_2) [23]. It has been reported that the installed TCG202V16 engine has electrical efficiencies of above 42% with an overall increase of the energy efficiencies on site from less than 45% to around 85% [24] [23].

6.3 PR 3: Mars Cogeneration, Wyong

Mars is a global food processor who owns the Masterfoods brand in Australia. They make sauces and process herbs which are sold mostly in Australia with about 140 different products in all. The company has a global aim to be carbon neutral by 2040 [25].

They have a large plant on the Central Coast at Wyong, which was emitting 10,400 tonnes of carbon a year. Mars recently spent nearly $2.5 million to build a cogeneration plant to help reduce its carbon emissions. The plant is a V20 natural gas fired engine that produces 1.4MW of power that covers about 75% of the power needed for the site [25].

Burning natural gas to produce electricity and capturing the waste heat generated in the manufacturing process, Mars are getting 80% energy efficiency from incoming fuel [25].

7.0 Recent Upgrade Works in Australia

The types of boilers in use across Australia's Meat Industry consist of the following:

- Coal Boilers
- Diesel/Oil Boilers
- Gas Boilers (Both Natural Gas and LPG)
- Methane Boilers
- Biomass Boilers.

There are a number of co-generation plants across the country, with significant potential for many more, however tri-generation plants remain under-represented. Many of the steam systems existing are oversized due to plant changes over the last 20 years, and many of the larger steam boilers are quite old and may need replacement in the coming years.

There is therefore a significant need for knowledge enhancement and information exchange.

Funding supplied by the federal government under the Clean Technology Investment (Food and Foundries) Fund for CAL's, biogas, boiler upgrade and heat recovery systems is summarised in Table 12: Clean Technology (Food and Foundries) Funding for the Meat, Poultry and Small Goods Manufacturing Industry. This included red meat processing facilities, chicken processing and small goods manufacturing.

Table 12: Clean Technology (Food and Foundries) Funding for the Meat, Poultry and Small Goods Manufacturing Industry [26]

COMPANY NAME	DESCRIPTION	GRANT SUPPLIED
A.J. Bush & Sons (Manufacturers) Pty Ltd	Installation of covered anaerobic lagoon to capture methane and feed into boiler	$3,117,682
Bartter Enterprises Pty Limited	Replace coal boiler with second-hand gas boiler	$144,278
Cool-Off Pty Ltd	Replace 2 existing boilers with 2 high efficiency reconditioned gas boilers	$204,272
M C Herd Proprietary Limited	Replace steam boiler with high efficiency hot water boiler with heat recovery and economiser	$162,173
Milne Agrigroup Pty Ltd	Installation of new spin/ re-chiller system	$1,015,620
Moo Premium Foods Pty Ltd	Installation of new generation gas boiler	$59,416

Baiada Poultry Pty Limited	Installation of flash steam recovery system	$48,909
RL Adams Pty Ltd	Methane extraction and recovery for use in biogas generators	$333,823
Derby Industries Pty Ltd	Replacement of boilers, installation of new state-of-the-art energy capture and steam recovery capabilities including flue gas economizers and flash recovery energy management equipment	$1,186,028
Valley Feeds Pty Ltd	Installation of flash steam recovery	$45,882
Greenham Tasmania Pty Ltd	Modify current boiler to enable co-combustion of biomass (pyrethrum briquettes and paunch waste)	$398,016
T & R (Murray Bridge) Pty Ltd	Convert a single meal processing line into two high efficiency process streams; replace 4 natural gas fired boilers with 2 new fully automated boilers capable of burning natural gas and biogas; replace blood dryer with a more energy efficient blood dryer; and replace current odour burners with a bio-filter.	$3,248,214
Teys Australia Beenleigh Pty Ltd	Installation of 34ML covered anaerobic lagoon and capture of biogas to offset natural gas consumption	$2,825,000
Teys Australia Meat Group Pty Ltd ATF the Consolidated Meat Processors Unit Trust	Installation of 2 30ML covered anaerobic lagoons to capture biogas for combustion on-site to offset black coal consumption	$4,169,000
Cedar Meats (Aust) Pty Limited ATF the Cedar Meats	Replace boiler network with high efficiency boiler and heat	$212,512

Discretionary Trust	exchanger	
E. C. Throsby Pty Limited	Installation of new high efficiency burner and PLC	$38,663
JBS Australia Pty Limited	Installation of covered anaerobic lagoons, capture of biogas, modification of boiler	$4,385,226
A.J. Bush & Sons (Manufactures) Pty Ltd	Installation of covered anaerobic lagoons, capture of biogas, and installation of new biogas boiler replacing black coal boilers	$6,184,589
D'Orsogna Limited	Upgrade 2 existing steam boilers, install economizer	$96,152
Teys Australia Southern Pty Ltd	Installation of 6MW dual fuel boiler (biogas and natural gas)	$328,696
V&V Walsh Pty Ltd ATF GMW Trust/RT9 Trust	Replacement of two 4MW fire tube boilers used to produce steam with two 4MW water tube boilers	$279,258
Wodonga Rendering Pty Ltd	Installation of natural gas fuelled tri-generation plant	$1,053,500

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9.0 Glossary of Terms

ABSORPTION CHILLER	A cooling machine that uses heat as the primary source of energy for driving an absorption refrigeration cycle to deliver coolth.
BASE LOAD	The level of demand, for heat or electricity, that exists for the majority of the operating period.
BASE-LOADED DESIGN AND OPERATION	An operating mode in which the combined heat and power (CHP) system is interconnected to the electrical grid and sized to meet the site's base-load requirements. By operating in this mode, part-load operation is avoided, no redundant capacity is required, and only supplemental power in excess of the base load is purchased from the electric utility.
BOILER EFFICIENCY	A value that characterises the amount of heat captured by the boiler or HRSG and transferred to the water, compared to the heat input. Boiler efficiency is a function of boiler losses and combustion losses.
BOTTOMING CYCLE	A heat-recovery scheme in which high-temperature thermal energy is produced and first used for industrial applications such as glass processing and metal smelting furnaces. Waste heat recovered from the industrial process is then used to drive a turbine to produce electric power.
BTU	British Thermal Unit – unit of energy equal to about 1055 joules
CO-GENERATION	AKA combined heat and power (CHP) is the use of a heat engine or power station to simultaneously generate electricity and useful heat.
COMBINED CYCLE	A term referring to the combination of two or more heat-recovery schemes to extract the most energy from the fuel. Typically, the exhaust from a gas turbine that is coupled to an electrical generator is used to produce steam that then drives a steam turbine coupled to another electrical generator. This increases the efficiency of electricity generation to about 50%.
COOLTH	The term for energy supplied where the temperature is lower than the starting point – effectively the opposite of Heat and the product of a chiller.
GAS TURBINE	A rotating machine that converts the chemical energy of fuel into mechanical energy. Basic elements of a gas turbine are the compressor, combustion chamber, and turbine. In operation, fresh air is drawn in by the compressor and forced into the combustion chamber. Inside the combustion chamber, the compressed air mixes with the fuel, and combustion occurs. During combustion, the chemical energy in the fuel is released to produce high-temperature combustion products that expand through the turbine and cause rotation.
HRSG	Heat-recovery steam generator. An unfired or supplementary fired heat exchanger that uses thermal energy to produce hot water or steam. The main application for unfired HRSGs is waste heat recovery and steam production from gas turbine

	exhaust. Supplementary fired HRSGs for gas turbine applications include gas-fired or oil-fired burners that augment the steam or hot water generating capacity of the exhaust gas stream.
ISOLATED DESIGN AND OPERATION	An operating mode in which the CHP system is sized to meet the site peak with reserve allowance for short-term power transients and to operate with no connection to the electrical grid. By operating in this mode, no electricity purchases are required.
KW AND KWH	kW = kiloWatt, a measure of electrical demand being 1000 Watts. A kWh is a measure of energy consumption, and represents 1kW in constant use for 1 hour.
LOAD-TRACKING	An operating mode for a CHP system that is designed to track either the site's thermal or electric load. By operating in this mode, supplemental power purchases, heat rejection, or supplemental thermal energy may be required, but both electric and thermal approaches can be designed to supply the site's peak requirements.
MMBTU	A unit of measure for heat (one million British thermal units).
MW AND MWH	MW = MegaWatt, a measure of electrical demand being 1000 kiloWatts. A MWh is a measure of energy consumption, and represents 1MW in constant use for 1 hour.
STEAM TURBINE	A rotating machine that converts the kinetic energy of moving steam into mechanical energy. Steam turbines are constructed with a stationary set of blades (called nozzles) and a moving set of adjacent blades (called buckets or rotor blades) installed within a pressure-retaining housing. Stationary nozzles accelerate the steam to high velocity by expanding it to lower pressure while the rotating blades change the direction of the steam flow to produce torque. Steam turbines are subdivided into two principal turbine types, impulse and reaction, depending on the way they direct steam flow.
TOPPING CYCLE	A heat-recovery scheme in which the energy in fuel is first used to generate electricity. Waste heat from the prime mover is then recovered and used for process heating or cooling applications.
TRI-GENERATION	Also known as combined cooling, heat and power (CCHP) refers to the simultaneous generation of electricity and useful heating and cooling from the combustion of a fuel or a solar heat collector.
WCMG	Waste Coal Mine Gas – natural bodies of gas emitted from a coal mine that can either be emitted to atmosphere or captured and used to run a gas turbine to produce electricity.

Appendix B: In-Situ Boiler Review

Table of Contents

1.0 Executive Summary

The red meat industry is continually searching for efficiency improvements to increase both productivity and international competitiveness. A key area of major expense in operational costs is in ***steam production*** within each major facility, which alongside ***refrigeration*** are major cost inputs to energy and maintenance budgets. ***Electricity*** imported from the National Grid is the third in the energy cost tripartite.

Electricity assets serving meat processors are likely to be able to carry the capacity required of the meatworks' peak output capacity from its entire history, and as such the pricing structure of the power tariffs reflect a take-or-pay component that penalizes low production.

Both the steam and refrigeration plant are highly capital intensive to establish or replace. As a result, it is typical to see aging equipment and technology in place in meat processing facilities, with an additional X-factor being that the original design brief for the boiler and compressors was highly likely to be addressing a different operating methodology within the plant, different kill-floor, bi-product and boning technologies. Thus it is not uncommon for boilers to be oversized, while refrigeration can also have redundant plant.

This In-Situ Boiler Review would find oversized electrical assets, aging boiler systems and oversized refrigeration plant that this report was commissioned. The findings at the older plants visited held that suspicion be true (although Plant A are in the midst of an upgrade project), while Plant C was clearly state-of-the-art, yet could still have taken an additional efficiency gain through tri-generation.

Newer technologies such as Co-Generation and Tri-Generation plants where electricity, heat and potentially cooling is produced are becoming more feasible with rising energy costs and fiscal support measures from the Federal Government. Only recently has there been any real movement in the use of dual purpose infrastructure for steam and refrigeration production. While on the face of it the concept of utilising shared infrastructure for the production of heat and coolth seems counter-intuitive, the reality is that waste heat is simply an energy source that can be harnessed for a number of productive purposes that include electricity generation and refrigeration.

With the increased supply costs of energy, new technologies come with new ways of thinking and potential changes in infrastructure and processes. Attractive returns for major infrastructure upgrades with simple paybacks of between 2 and 5 years are possible.

Four facilities accepted the opportunity to take part in the study, the facilities are located across Queensland, New South Wales and Northern Victoria. The four facilities were;

- Northern Victoria — Plant A
- South NSW — Plant B
- South-East Queensland — Plant C
- South Queensland — Plant D

2.0 Introduction

The primary goal of this In-situ Boiler Review was to obtain a greater understanding of the boiler technologies and processes in use at red meat processing facilities throughout Australia and how any waste heat might be recovered or heat itself produced in a more efficient way.

A number of key questions were posed, including:

- How do major facilities produce steam and what condition are the boilers in?
- Which fuel source do they utilize?
- What technology is utilized and to what level of efficiency?
- Is there excess steam being produced or able to be produced?
- What infrastructure-based energy efficiency options are open to producers?
- Are there economic benefits on offer that justify major upgrades in technology and efficiency?

A key aim was therefore to understand the status of steam generation currently, and investigate ways to bring aged steam powered meat work facilities up-to-pace with greater energy efficient measures.

This could potentially be achieved by:

- Decreasing the amount of heat energy lost throughout the process, or
- Replace old equipment with new, or
- Augment existing systems with new technologies as “bolt on” devices.

There are three main options that are apparent from the site inspections:

- old boilers, potentially coal fired, with more modern natural gas and biogas fired boilers. The associated emission reductions, availability, cost and technical challenges need to be addressed when analysing any choice of boiler fuel, however if it is readily available then natural gas is a leading option. A gas system can be supplemented with biogas captured from an anaerobic wastewater treatment process located onsite.
- Retrofit or install a new co-generation system. Co-generators are generally gas-fired and allow for the simultaneous production of steam and power, thus reducing the dependence on utility supplied power and replacing standalone boilers. A cogeneration system can be sized to either meet the thermal energy usage or the electrical energy usage for the site, or both. They become viable when the potential site has high annual operating hours, at least 500kW average electricity demand, a yearly thermal load of 2000 GJ+, cogeneration fuel costs that are low when compared to electricity rates and a thermal demand closely matching the electrical demand. Retrofitting a boiler with cogeneration technology is possible if the existing boiler is oversized and is producing excess steam. This excess steam could be used to create power, heating, coolth or a combination of all.
- Retrofit Tri-generation, which is an extension of co-generation. It involves simultaneously producing combined heating, coolth and power. Tri-generation is achieved by using the waste heat available to drive an absorption chiller as well as a power generator. The technology can be put to good use in the red meat processing industry due to the requirement for steam, refrigeration and electricity at red meat processing facilities.

For each site investigated, the primary aim was to identify bottom line improvements and an increase in plant efficiency that could potentially be copied by other industry members facing similar issues and technological/fuel source challenges.

A Cost Benefit Analysis (+/- 30%) was undertaken for the most likely actions applicable at each facility.

Obvious and costly steam leaks from piping

3.0 Current Heat Recovery Status

Each of the four facilities had at least one form of heat recovery implemented within their plant. All were in good condition with respect to their age and operating equipment.

Each facility's current heat recovery measures are detailed below.

PLANT A

Plant A addressed much of their waste heat issues by installing a new multi-output generation plant at their facility. The newly installed 2MW Tri-generation unit is capable of producing up to:

- Electricity: 2,000 kW
- Steam: 630kW
- Hot water: 978 kW

As a result the unit has the potential combined production of 3,608kW of energy when fully operational.

Along with the new Tri-gen plant, Plant A also possesses three other boilers (2x 6MW and a 3MW unit) all of which are fired by natural gas, which is already a very efficient source of boiler energy, and is available from the Victorian gas network.

With all three boilers and the Tri-gen facility all powered by natural gas, there is further potential to collect and harness bio-gas from the site's wastewater treatment facility.

Chiller rooms, piping and equipment are all kept in a good condition with very little to no icing present, which indicated that the cooling system is running in an optimum condition. Lagging is on most equipment and pipe work, to reduce heat loss to the atmosphere.

PLANT B

With three gas fired boilers in operation within Plant B facility they are already utilising natural gas as an efficient fuel for creating hot water and steam. The cold rooms and equipment are kept in a good condition with lagging present on most of the equipment and pipe work, to help reduce heat loss.

Waste hot water from the flue gas condenser is recovered to assist with the sterilization and wash the down of the slaughter floor.

There is currently an excess of hot water produced that could be harnessed for useful purposes.

PLANT C

The Plant C facility is a *'state of the art'* facility in very good condition, operating a coal fired Fluidised Bed Boiler (FBB) that provides 8MW thermal to steam for the continuous cooker, sterilisation hot water and heat exchanger.

On boiler start up the steam is sent to a heat exchanger which produces warm water for the plant. Once the rendering plant is ready to start the steam is passed through the heat exchanger producing hot water for sterilisation.

The rendering plant uses a condenser on the cookers flue stack which receives town water and in turn produces warm water for the plant when the cooking process is in operation.

Heat Storage and Piping

PLANT D

Plant D operates two gas boilers that receive potable water from a bore at higher than normal temperatures, sometimes up to 40°C. This provides the warm water demand on the site and reduces the load on hot water generation. The two gas fired boilers provide the plant steam demand which is primarily a continuous meal cooker, blood cooker, sterilization water heating and some small intermittent parasitic loads for warming the tallow tanks and tallow decanters.

Upon start-up, or when rendering is not in operation, the steam is used to generate sterilization water through a heat exchanger. Once the plant is rendering, the flue gas from the cooker is put to a heat exchanger to produce hot water for the facility. To assist with cooling the flue gas, another heat exchange utilises pond water to condense the gas where it is then processed through an odour burner.

The chiller plant is in good condition, the insulation on the piping is working well and little icing is present.

Gas Powered Rotating Disc Cooker

4.0 Technology Integration

Heat recovery as a concept is a secondary stage action, following the reduction of heat loss through uninsulated equipment or steam leaks. In some cases it is a tertiary action following fuel replacement.

Heat recovery by definition takes quite complicated forms – including heat exchangers, steam powered generators, and Co/Tri-generation systems. These require major investments and a strong understanding of the electrical and heat needs at the plant, especially in how the need for each correlates.

They are also only viable when a site has an excess of heat and a separate need for another source of energy to perform a task not performed by the existing steam equipment – such as refrigeration or power generation. As such are more predominantly implemented in older plants that have had decades of process creep and changes in product formats to cope with.

Integrating new technology into an older site can be particularly difficult. Key areas to be cautious of include:

- Sensitivity of highly computerised equipment to power fluctuations and harmonics;
- Mismatch of reaction times between new and old equipment;
- Mismatch of operating temperatures, pressures and capacities;
- Capacity of old pipeworks and pressure vessels to effectively handle the output of new equipment especially where pressures or throughput are increased or decreased;
- Long term fuel availability and fuel storage;
- In-house capacity to operate and maintain new equipment alongside old equipment;
- Spatial constraints;
- Power system capacity for both import and export of electricity;

As a result while the projects proposed here are possible, they are far from an integrated solution. These projects have been cost and benefit estimated to +/- 30%, thus are indicative at best, and can only be used to decide if further investigation and perhaps detailed design investigations are warranted.

5.0 Site Opportunity Concepts

PLANT A

Plant A has multiple areas that could potentially be altered to utilise waste heat and/or reduce the facility's natural gas consumption. The heat exchanger/blood dryer option from this site is likely to be a far more financially viable option than an absorption chiller.

Heat Exchanger

When facing expansion, Plant A could avoid installing an additional boiler by installing a Heat Exchanger that takes its heat feed off the current boilers' flue stacks. The heat extracted could potentially run the blood drier. Redirecting heat from the flue stacks to the blood drier will therefore reducing the gas demand from the main gas supply that's currently running at capacity, freeing up gas for other purposes.

To ensure the heat transfer unit is operating at its optimal capacity additional research will be required into the availability of heat from the boilers, and the correlation of the blood drier operation times with the boilers. Additionally there may be spatial constraints at the boilers' stacks.

Absorption Chiller

An option to reduce the site's overall power consumption may be to install an absorption chiller on the exhaust flue stack of one or more of the boilers.

An absorption chiller will be capable of providing cooling to the cold rooms along with cold water throughout the facility and depending upon the chiller size, it may be able to provide enough cooling to run the freezers.

There is significant doubt however that a compelling financial case could be made for the absorption chiller, when a heat exchanger on the same flue stacks would be a far more attractive option financially and also free up much needed gas capacity.

PLANT B

The Plant B is a relatively new meat processing site. Prior to consideration of any heat recovery options, it is recommended that a number of hot water leaks in the pipework, connections and valves throughout the facility be sealed, and the uninsulated pipes be lagged.

There is a need onsite to cool the Cooker's flue gases, which consumes significant quantities of town water.

The existing unused boiler flue stack cooling tower could be utilized to reduce the incoming town water supply temperature. Chilling the cooling water to 2-4°C from the incoming town supply of 16-20°C may reduce the quantity of cooling water required by as much as 20%, saving not only waste water but also limiting the import cost of town water.

It appears most likely from initial viewing that a waste water recovery unit to chill town water would provide the best returns for this site, with minimal capital outlay and a significant cost reduction. Other capital intensive options include:

Tri/Co-generation Upgrade

The site is well suited to a Tri-generation or Co-generation facility. A similar sized Tri-generation plant to that of Plant A, modified to suit the specifics of the Plant B operation, could produce ~900kW of hot water that would make redundant the hot water boiler currently in operation. Potentially it could also produce coolth for refrigeration depending on the final format of the system.

A Tri-generation plant will reduce or completely negate the gas consumption of the hot water boiler, while potentially reducing the electricity required to operate the cold rooms and produce electricity locally at a cost below that of grid power for use across the entire site. A financial feasibility study is required to determine how viable a Tri-gen plant would be.

Steam Powered Generator

A steam powered generator may also be a viable option, and would have a significantly reduced capital cost over Tri-generation. The existing hot water production capacity is significantly higher than that which is used onsite, with large amounts of excess hot water lost due to overflowing tanks.

This excess hot water could be harnessed in a steam generator with suitable plant operations alterations, and could result in power export to the National Grid. Numerous items such as electrical asset conditions need to be investigated before any potential project could be seriously considered.

Potentially a 700kW steam turbine could be installed, with an annual energy production of 2,100MWh per year, based on a 60hr week, 50 weeks a year production schedule.

This would cover the entire electrical requirements of the facility all year round, potentially saving ~$0.6 Million per year based on current electricity costs. Detailed technical investigations into correlations between electricity use and hot water availability are needed to confirm the technical and financial viability.

PLANT C

A number of options for Plant C have been reviewed, however none meet the basic technical and economic feasibility tests.

Prospectively, they could install an absorption chiller and co-generation equipment, however there are spatial issues in play that mean the equipment would need to be remote from the current heat sources, making the project technically challenging and unusually expensive. Additionally the inexpensive nature of Queensland black coal as a fuel supply contrasts with the higher (and potentially escalating) cost of natural gas in Queensland.

A steam turbine could also be considered within the coal fired facility, however it may then require an increase in coal throughput and restrict steam availability to the rest of the plant, thereby putting at risk the primary reason for the boiler's existence, rather than harnessing waste.

There are a number of minor repairs that could increase heat retention, though there are no major upgrades required for the facility. Insulation on the pipework requires some attention and two tallow tanks which receive steam were uninsulated. While these would lose significant heat to atmosphere, they operate intermittently therefore it may not be a major concern to the facility at this stage.

PLANT D

A number of items were noted that result in significant energy loss that could be rectified through minor repairs and redesign, including:

- the lack of insulation lagging on pipes throughout the facility
- the steam escaping through a passing steam trap on the steam/hot water Heat Exchanger
- drains from the heat exchanger were in the open position allowing steam to vent continuously
- some of the condensate was being captured by a steam trap, though the method currently in operation allows for a lot of steam to pass through the trap. The condensate could better be recovered by a flash vessel, regardless there should be no steam passing the steam trap.

Steam-Trap passing large quantities of steam

The site is currently installing a covering over its anaerobic lagoon to collect biogas for use in the boilers. The initial research indicates a supplementary project to this, involving cogeneration, could deliver a high value heat and power generation using for the site.

Trigeneration

A Process Flow diagram (PFD) for the plant steam, water and waste water was produced and is undergoing revision by the plant operator to confirm accuracy.

Without PFD confirmation, it is difficult to validate the options available to better utilize the heat/steam process throughout the plant. Plant D uses natural gas and is moving to a biogas mix in the boilers, thus is a prime candidate for a co/tri-generation plant to produce steam, electricity and either hot water or refrigeration.

The site is not spatially difficult to work in, has suitable equipment for direct changeover, a need for significant heat and power, and a local source of gas, meaning it is a very strong research candidate for a cogeneration plant.

Absorption Chiller

Current there is significant waste energy from the cooker flue gas heat exchanger, in the form of hot water, injected into the anaerobic lagoon. This energy could be used for an absorption chiller to help offset the existing chiller plant.

The chiller plant is in good condition, making it suitable for augmentation with a absorption chiller. The insulation on the piping is working well and little icing is present, indication excellent working conditions.

However there is very little room inside the chiller plant room for the addition of an absorption chiller, thus spatial constraints may prevent an absorption chiller from being a viable option without further alterations to the operating protocols and physical equipment layouts in the plant room.

6.0 Case Study 1: PLANT A

Concept Description: Recovering heat for the blood dryer.

Cost-Benefit Analysis Inputs:

- Capital Cost of Heat Exchanger Installation: $500,000
- Resultant Operational Savings Per Annum: $207,900, in Year 1.
- Boiler Operation: 8 hrs per day
- Heat Transfer Rate: 55%
- Gas Usage: 18GJ/hr
- Daily Gas Savings: 79.2GJ
- Gas Price: $10.50/GJ

Results:

- Simple Return on Investment: <3 Years
- Rate of Return: ~35%

The following table shows, in simple terms, the progressive payback of Capital Expenditure progressively escalated at 4.5% for inflation, ignoring such factors and borrowing costs, discount factors, maintenance etc that would be taken into account in a detailed investment decision. Additionally, savings are discounted by 4.5% to cater for inflation. As a result these are indicative +/- 30% accuracy numbers providing a simplistic return period in years, based on a conceptual project outline.

END OF YEAR	0	1	2	3
Capital Expense Outlay	$500,000	0	0	0
Escalation/Devaluing of Savings		$22,500	$32,868	$24,150
Operational Savings	$0	$207,900	$198,545	$188,610
Balance yet to be Recovered	$500,000	$314,600	$139,568	Credit of $34,827

It can be seen that a simple rate of return of slightly less than 3 Years could be achieved.

7.0 Case Study 2: PLANT B

The suggested upgrades that were considered in the feasibility analysis show that they could be viable projects to be considered by the facility. Though without knowledge of the facility's financial situation and debt capacity, an internal financial model will be needed to confirm these investments.

The proposed Trigeneration plant at first glance appears to be a reasonable investment with a simple rate of capital return of less than 5 years. However there may be additional operational costs that make significant changes to the annual savings, which have been based solely on the gas acquisition costs. The primary technical issues come down to the facility's gas line capacity.

Reducing the quantity of waste water onsite can be achieved by many means though the simplest maybe utilising the facilities Cooling Tower to assist condensing the flue stack gases with an approximate 20% water requirement reduction.

Concept Description: Tri-generation Plant.

Cost-Benefit Analysis Inputs:

- Capital Cost of Generator & HV Gear Installation: $2,600,000
- Resultant Operational Savings Per Annum: $820,525, in Year 1.
- Peak Electrical Demand: 1282kW
- Average Electrical Demand: 566kW
- Yearly Electricity Use: 4,958,160kWh
- Average Electricity Price: $0.26/kWh
- Yearly Electricity Cost: $1,289,122
- Equivalent Gas Use: 44,632GJ
- Gas Price:$10.50/GJ
- Gas Cost/Year: $468,525
- Assumed Electrical Efficiency: 40%
- Boiler Operation: 8 hrs per day
- Heat Transfer Rate: 55%

Results:

- Simple Return on Investment: <4 Years
- Rate of Return: ~25%

The following table shows, in simple terms, the progressive payback of Capital Expenditure progressively escalated at 4.5% for inflation, ignoring such factors and borrowing costs, discount factors, maintenance etc that would be taken into account in a detailed investment decision. Additionally, savings are discounted by 4.5% to cater for inflation. As a result these are indicative +/- 30% accuracy numbers providing a simplistic return period in years, based on a conceptual project outline.

END OF YEAR	0	1	2	3	4
Capital Expense Outlay	$2,600,000	0	0	0	0
Escalation/Devaluing of Savings		$117,000	$122,265	$87,518	$14,337
Operational Savings	$0	$820,578	$738,650	$748,386	$714,708
Balance yet to be Recovered	$2,600,000	$1,896,424	$1,161,187	$429,791	CREDIT OF $299,254

It can be seen that a simple rate of return of less than 4 Years could be achieved.

Concept Description: Waste Water Recovered to Chill Town Water

Cost-Benefit Analysis Inputs:

- Capital Cost: $100,000 in engineering and reconstruction using existing assets.
- Resultant Operational Savings Per Annum: $70,100, in Year 1.
- Operation: 8 hrs per day
- Cost/kL of Water: $1.75
- Quantum of Water available at 60ºC: 7,200l/hr
- Gas Usage: 1.205GJ/hr
- Gas Price: $10.50/GJ

Results:

- Simple Return on Investment: 1.4 Years
- Rate of Return: 70%

The following table shows, in simple terms, the progressive payback of Capital Expenditure progressively escalated at 4.5% for inflation, ignoring such factors and borrowing costs, discount factors, maintenance etc that would be taken into account in a detailed investment decision. Additionally, savings are discounted by 4.5% to cater for inflation. As a result these are indicative +/- 30% accuracy numbers providing a simplistic return period in years, based on a conceptual project outline.

END OF YEAR	0	1	2
Capital Expense Outlay	$100,000	0	0
Escalation/Devaluing of Savings		$4,500	$8207
Operational Savings	$0	$70,100	$63,440
Balance yet to be Recovered	$100,000	$34,400	Credit of $20,833

It can be seen that a simple rate of return of slightly less than 2 Years could be achieved.

8.0 Case Study 3: PLANT D

Concept Description: Tri-generation system.

Cost-Benefit Analysis Inputs:

- Capital Cost of Generator & HV Gear Installation: $2,600,000
- Resultant Operational Savings Per Annum: $287,500, in Year 1.
- Average Electrical Demand: 2700kW
- Yearly Electricity Use: 23,652,125kWh
- Average Electricity Price: $0.135/kWh
- Yearly Electricity Cost: $3,193,037
- Equivalent Gas Use: 194,845GJ
- Gas Price:$14.30/GJ
- Gas Cost/Year: $2,786,394
- Assumed Electrical Efficiency: 43.7%

Results:

- Simple Return on Investment: ~10 Years
- Rate of Return: 10%

END OF YEAR	0	1	2	3	4
Capital Expense Outlay	$2,600,000	0	0	0	0
Escalation/Devaluing of Savings		$117,000	$122,264	$114,828	$107,640
Operational Savings	$0	$287,505	$274,568	$262,213	$250,401
Balance yet to be Recovered	$2,600,000	$2,429,495	$2,277,191	$2,129,806	Debit of $1,987,045

It can be seen that a simple rate of return would take up to 10 years, without escalated fuel costs positively affecting the result over that period (which would be highly likely).

9.0 Appendix 1 - Glossary of Terms

ABSORPTION CHILLER	A cooling machine that uses heat as the primary source of energy for driving an absorption refrigeration cycle to deliver coolth.
BASE LOAD	The level of demand, for heat or electricity, that exists for the majority of the operating period.
BASE-LOADED DESIGN AND OPERATION	An operating mode in which the combined heat and power (CHP) system is interconnected to the electrical grid and sized to meet the site's base-load requirements. By operating in this mode, part-load operation is avoided, no redundant capacity is required, and only supplemental power in excess of the base load is purchased from the electric utility.
BOILER EFFICIENCY	A value that characterises the amount of heat captured by the boiler or HRSG and transferred to the water, compared to the heat input. Boiler efficiency is a function of boiler losses and combustion losses.
BOTTOMING CYCLE	A heat-recovery scheme in which high-temperature thermal energy is produced and first used for industrial applications such as glass processing and metal smelting furnaces. Waste heat recovered from the industrial process is then used to drive a turbine to produce electric power.
BTU	British Thermal Unit – unit of energy equal to about 1055 joules
CO-GENERATION	AKA combined heat and power (CHP) is the use of a heat engine or power station to simultaneously generate electricity and useful heat.
COMBINED CYCLE	A term referring to the combination of two or more heat-recovery schemes to extract the most energy from the fuel. Typically, the exhaust from a gas turbine that is coupled to an electrical generator is used to produce steam that then drives a steam turbine coupled to another electrical generator. This increases the efficiency of electricity generation to about 50%.
COOLTH	The term for energy supplied where the temperature is lower than the starting point – effectively the opposite of Heat and the product of a chiller.
GAS TURBINE	A rotating machine that converts the chemical energy of fuel into mechanical energy. Basic elements of a gas turbine are the compressor, combustion chamber, and turbine. In operation, fresh air is drawn in by the compressor and forced into the combustion chamber. Inside the combustion chamber, the compressed air mixes with the fuel, and combustion occurs. During combustion, the chemical energy in the fuel is released to produce high-temperature combustion products that expand through the turbine and cause rotation.
HRSG	Heat-recovery steam generator. An unfired or supplementary fired heat exchanger that uses thermal energy to produce hot water or steam. The main application for unfired HRSGs is waste heat recovery and steam production from gas turbine exhaust. Supplementary fired HRSGs for gas turbine applications include gas-fired or oil-fired burners that augment the steam or hot water generating capacity of the exhaust gas stream.
ISOLATED DESIGN AND OPERATION	An operating mode in which the CHP system is sized to meet the site peak with reserve allowance for short-term power transients and to operate with no connection to the

	electrical grid. By operating in this mode, no electricity purchases are required.
KW AND KWH	kW = kiloWatt, a measure of electrical demand being 1000 Watts. A kWh is a measure of energy consumption, and represents 1kW in constant use for 1 hour.
LOAD-TRACKING	An operating mode for a CHP system that is designed to track either the site's thermal or electric load. By operating in this mode, supplemental power purchases, heat rejection, or supplemental thermal energy may be required, but both electric and thermal approaches can be designed to supply the site's peak requirements.
MMBTU	A unit of measure for heat (one million British thermal units).
MW AND MWH	MW = MegaWatt, a measure of electrical demand being 1000 kiloWatts. A MWh is a measure of energy consumption, and represents 1MW in constant use for 1 hour.
STEAM TURBINE	A rotating machine that converts the kinetic energy of moving steam into mechanical energy. Steam turbines are constructed with a stationary set of blades (called nozzles) and a moving set of adjacent blades (called buckets or rotor blades) installed within a pressure-retaining housing. Stationary nozzles accelerate the steam to high velocity by expanding it to lower pressure while the rotating blades change the direction of the steam flow to produce torque. Steam turbines are subdivided into two principal turbine types, impulse and reaction, depending on the way they direct steam flow.
TOPPING CYCLE	A heat-recovery scheme in which the energy in fuel is first used to generate electricity. Waste heat from the prime mover is then recovered and used for process heating or cooling applications.
TRI-GENERATION	Also known as combined cooling, heat and power (CCHP) refers to the simultaneous generation of electricity and useful heating and cooling from the combustion of a fuel or a solar heat collector.
WCMG	Waste Coal Mine Gas – natural bodies of gas emitted from a coal mine that can either be emitted to atmosphere or captured and used to run a gas turbine to produce electricity.

10.0 Appendix 2 – Relevant Technologies

Readers should refer to the preceding document to this for a full description of technologies, in the paper titled "Literature Review: Heat Recovery in Steam Generation in Red Meat Processing Facilities" dated 28 April 2014, authored by SMEC.

Here is a very brief explanation of some applicable hot water and steam technologies for red meat facilities.

Coal Fired Boilers
Coal fired boilers are among some of the oldest forms of energy and heat production though there have been some steps forward in this field.

While coal boilers have increased in efficiency over time, they are still one of the least most efficient fuel sources in terms of conversion rates from input to output, and have a high public profile in terms of emissions produced. When sites are located near coal fields where overburden can be obtained, coal remains the most cost effective boiler fuel available. The cost of Coal in northern Australia is still far cheaper than other fuel sources.

Natural Gas Fired Boilers
Natural Gas is a far more efficient alternative to coal on the input-output ratio, while also emitting significantly less (around half) the emissions of coal. Politically it is therefore far more palatable.

Gas is also far more available in the Southern states due to extensive gas piping networks and a lack of quality coal available via overburden.

Gas boilers can also re-use waste generated at site through the use of digesters producing biogas.

Bio-Gas Fired Boilers
Bio-Gas is produced from waste being pumped into a digester (either mechanical digester or an anaerobic lagoon) to break down animal waste, and create gas that can be collected and used in place of natural gas.

Bio-Gas can contain harmful impurities that can potentially damage standard natural gas equipment if it's not correctly treated prior to use.

Steam Turbines
There are two requirements for steam turbines;

- Hot water/steam at the required manufactures specifications, and
- Enough capital funds to afford such an investment.

The operational cost of installing the steam turbine on an existing system will be a minimal increase in fuel consumption to generate the electricity. Though depending upon the existing pressures and quality of steam currently in circulation this may not be an issue, if the existing pressures are sufficient.

Considering the capital required for installing HV switch gear, the investment may not be worth considering if excess energy cannot be completely used, stored or sold back to the grid, for extra revenue.

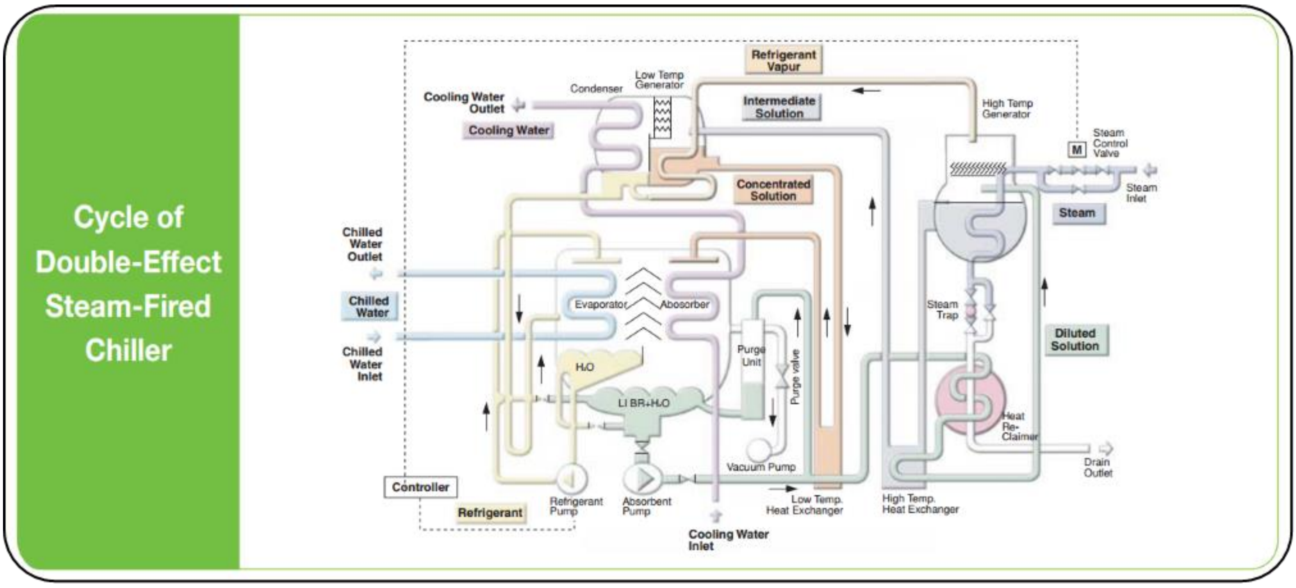
Mechanical Chillers

Mechanical chillers work on a series of pumps and compressors to operate the chiller, however there are multiple types of mechanical chillers such as Reciprocating, Screw and Centrifugal, though they all operate on the same basic principle of compression, condensing and expansion.

Absorption Chillers

Through the use of ammonia as a refrigerant, absorption chillers can be very efficient and safe means of supplying cooling throughout a facility.

Absorption chillers differ to conventional chillers by the use of steam or hot water to drive the cooling system in place of the conventional mechanical pumping system. By replacing electricity with steam it reduces the power consumption required to provide cooling throughout the facility.



Cycle of a Double Effect Steam Fired Li-Br Chiller

Solar Hot Water Systems

Solar hot water can be introduced to increase the incoming water temperature to the boilers and reduce primary fuel use.

11.0 Appendix 3 - Slow Take-Up in Absorption Chillers

Fuel Cost

Historically the low cost of fuel and electricity has supported traditional electric chillers in red meat processing facilities given their lower capital costs than absorption chillers.

However with rising fuel costs over the past (and projected) few years, the additional capital costs of absorption chillers are likely to be outweighed by the significant reduction in operating costs that they can derive as a result of harnessing waste heat.

Higher uptake rates are also leading to reduced engineering and capital costs, further contributing to the competitiveness of absorption chillers in the market.

A key difficulty with making a major change to a facility such as moving to absorption chilling is the significant alterations needed in terms of long term plant layout, especially for aging facilities where layouts have been ad-hoc in nature, and dependent on urgent growth, regulation changes or disruptive technology introduction.

Technology Competition

Additionally, absorption chillers need to compete attractively with other Capital Projects and Waste-to-Energy projects specifically as there is a limited pool of funds available in the red meat industry.

For example, a Coal Fired facility only has a small number of ways to maximise their efficiencies and reduce waste, one of which is to install an absorption chiller. Sizing the correct chiller for the application will be determined by well-known exhaust temperatures and pressures. The issues in this case will be the capital expenditure, spatial constraints and distance of chilled water or ammonia to blast freezers.

Competition for capital will then come from biogas projects – being either digesters or covering of an anaerobic lagoon. A covered lagoon is a relatively low expense, and assuming gas analysis is suitable for use in a boiler, provides a strong return on investment. Digesters have a higher capital cost but produce storage gas of a higher quality, thus may contribute to plant capacity limitation issues such as a constrained gas supply or expensive penalty costs on electricity demand tariffs.

Appendix C: Detailed Feasibility Study: Site D

Table of Contents

1.0 Executive Summary

This report forms part of the AMPC research project '2013/5011 Options to optimise heat recovery at red meat processing facilities'. It is a feasibility study into heat recovery options at a large Australian red meat processing facility.

The most attractive investment option identified was the installation of micro turbines that generate steam and power for use in the red meat processing facility. There appears a strong opportunity for this technology to be utilised within red meat processing facilities that are expanding or overhauling, and they have non-capital financing options that may allow rapid market penetration.

1.1 Investment Result

The site investigated has multiple technology options available to it. After all capital funding, operation and maintenance costs were considered, the estimated financial results for each option was predicted to be in the following ranges:

- positive Net Present Value (NPV) at the 25 year mark
- internal Rate of Return (IRR) of between 12% and 23%
- commercial Rate of Return (RoR) of between five and 12 years.

With the high competition for capital in a red meat processing facility, we found that it is highly unlikely that any of these opportunities would attract capital funding. The study site has a requirement for major capital works to deliver IRR of 50% with a maximum two-year RoR. None of these projects crossed that hurdle rate. As a result none of the options are considered commercially viable in a red meat facility at this time as a stand-alone project.

However, there is potential for a project to become viable if combined with a major overhaul or replacement of existing plant that has reached the end of its useful life under a hybrid maintenance/capital exercise, where major investment was planned and did not require anything more than direct like-for-like equipment replacement. This was not the case at the studied processing facility.

1.2 Research Results

Research into the multiple avenues of heat recovery has resulted in a handful of potential upgrades that could be implemented into red meat processing facilities across Australia. As all options will benefit the facility over the operational life of the unit, the question of the investment's viability arises.

Typically red meat facilities require a swift turnaround when it comes to capital expenditure. Two years is currently considered the repayment threshold. Such a small investment window is typically only held for maintenance and replacement work, so for major technology change to occur in heat recovery situations the technology change must occur coincidently with replacement works and capacity upgrades.

This short payback period requires highly efficient equipment to ensure the fastest possible payback period. Operators strongly prefer units that are modular, capable of being installed quickly without major disruption and upgraded over time.

The research into the studied red meat facility found that modular micro turbines are the best technology for this application, as they provide a small footprint, high efficiency and ease of integration into the existing facility. A five-year RoR from a 23% IRR delivered an NPV of $14.2M at year 25 from a capital investment of $2.7M.

1.3 Implementation Potential

While competition for capital in the red meat processing industry is intense, the implementation of heat recovery projects is highly unlikely outside of major overhaul programs or capacity upgrades. This is due to IRRs of 23% with a RoR of five years for the micro turbine at this site being well outside what is considered an acceptable investment window.

However, there is potential for attracting third-party investment to such returns. Commercial leasing or vendor finance are obvious choices in return for 10-year rental contracts that provide the funder with a strong return and do not affect processing facility capital works programs.

On the downside, the funder may seek firm 10-year contracts that could have penalty clauses for early termination that may be commercially damaging to processing facilities that have some risk of limited life spans or that need a major overhaul in the next decade to keep pace with technology changes in the industry.

1.4 Options Other than Micro Turbine Considered

Other technologies that were investigated are also noteworthy and could also attract third-party investment. All six options studied are technologically sound and provide positive financial results.

SMEC developed a decision matrix that weighted IRR, NPV, RoR and integration difficulties into the existing plant's operations.

- An overall rating of 1.5 to 2.0 delivered an investment-ready solution with a two-year RoR.
- A weighted score of 1.0 was considered to be a technology of worth that may attract third-party funding under acceptable terms and conditions.
- Anything less than 1.0 was deemed unlikely to attract investment in the red meat processing industry. These technologies would only be installed as a result of a full heat system replacement given the likely disruption to production and slow RoR.

MATRIX SUMMARY	
Micro-Turbine	1.0
ORC Recovery Unit	0.8
Absorption Chiller – Exhaust	0.6
Engine	0.5
Absorption Chiller – Waste Heat	0.5
Turbine	0.1

Even though micro turbines are considered a sound investment, they still do not meet the payback requirements of the studied site (less than two years); therefore, none of the investigated options are viable for this site given the current investment conditions.

2.0 Introduction

The in-situ boiler review report from AMPC's research project, entitled 'Heat Recovery in Steam Generation in Red Meat Processing Facilities', reviewed the physical attributes and potential initiatives at four major facilities in relation exclusively to steam generation and heat recovery options. That in-situ investigation identified Plant D as the best case study site of the four we visited as a full study site for a more detailed review.

Plant D was chosen for the following reasons:

- There was potential to replace the boiler with a cogeneration unit.
- The cogeneration unit initially reviewed had the capacity to supply all of the site's steam and hot water needs and provide high-value electricity as well.
- There are emerging technologies in the cogeneration and absorption-chiller field that had strong potential at the site, providing multiple optionality in the research and the potential to take an additional step into tri-generation, harnessing excess steam for refrigeration.
- Plant D has available space in and around the current plant rooms to expand the physical assets, which is commonly not the case in red meat facilities.
- Plant D has steam and power needs that are typical of the sampled red meat facilities reviewed previously, so it provided a good case study for the industry.

The in-situ boiler review identified a number of options for Plant D, as there were many areas that had strong heat recovery potential, such as absorption chilling off the excessive hot water the facility produces, along with a co or tri-generation system to supply the facility with heat and locally produced electricity on site.

This feasibility study addresses six heat recovery options available to Plant D, expanded from the in-situ boiler review as a result of further research into technology developments.

List of technologies that were investigated include:

- cogeneration turbine
- cogeneration engine
- absorption chilling
    - Flue gases
    - Waste hot water
- steam turbine generator
- micro-turbine cogenerator
- organic rankine cycle (orc) – heat recovery power box.

Each of these technologies is, in the right circumstances, technically viable in terms of process integration in a red meat processing facility, with outputs including heat, power and/or refrigeration.

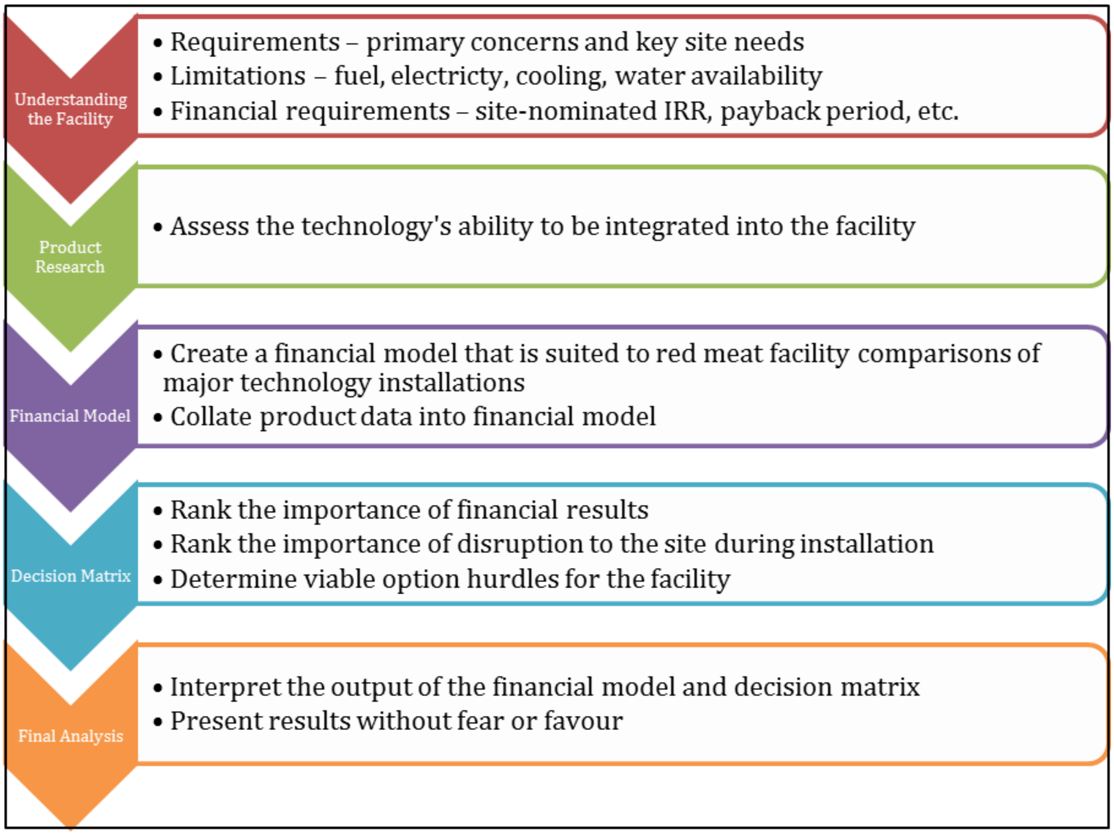
Each technology is readily available in Australia from reputable suppliers.

Each of the technologies was investigated further, priced and compared in a custom financial model to determine their installation attractiveness (IRR and RoR being the key indicators) and value to the plant over its life span (via a 25-year NPV).

3.0 Method

3.1 Background

The method used to determine the best-suited heat recovery projects for the facility is outlined in the following flow diagram.



3.2 Facility Requirements

The researchers interviewed the Plant D Operations Manager to determine critical investment decision triggers and gain a strong understanding of the management's inclination towards technology change, current major issues, overhaul timelines, constraints and capacity limitations.

Identifying viable heat recovery options for Plant D meant understanding:

- The facility's investment profile and capital hurdles
- The current state of equipment (identified during the site visit conducted in the in-situ boiler review)
- What the facility managers consider a reasonable level of capital expenditure
- The life span of the existing operation
- The interrelation with other facilities nearby and owned by the same parent company.

The following key points were identified:

- Plant D has limited capacity left in their incoming natural gas line.
  - The potential cost to install a new gas line to the facility was previously quoted at $1M.
- Plant D's parent company has strong competition for capital among a number of facilities.
  - The current requirement on capital payback is set at less than two years.
  - In the previous financial year a maximum RoR of 14 months was implemented on capital projects.
- Recycling of capital rapidly is a key concern of the parent company, so a rapid rates of return is required to ensure capital is effectively recycled.
  - IRR is not a great concern to the facility; however, it was broadly acknowledged that sound investments have an IRR of >20%.
  - NPV would be considered as a comparison tool for major maintenance/replacement/overhaul projects but given the short RoR window it was not part of the capital competition process.
- Sourcing capital was not considered a great concern provided RoR was short.
  - A realistic spend ceiling for the facility was nominated at $5M.
  - Investments greater than this would need major review and more rapid RoR as they may impinge on multiple projects across the company that had similar RoR.
- Plant D currently consumes a significant quantity of electricity.
  - A reduction of electricity costs would result in higher profits for the company.
  - Generation of electricity on site would have significant benefits as it may provide consistent production stability, whereas power quality currently was below what could be considered exemplary.
- Productivity is paramount to the operations.
  - Production outages for major construction works would be a major concern.
  - Improvements to the output of the facility would be considered highly favourable.

3.3 Decision Matrix Development

The researchers considered Plant D's specific requirements to develop a decision matrix that weighted the most critical investment decisions as the heaviest.

The decision matrix shown below is broken into four sections of viability: IRR, payback period RoR, capital expenditure (CAPEX) and integration into the facility.

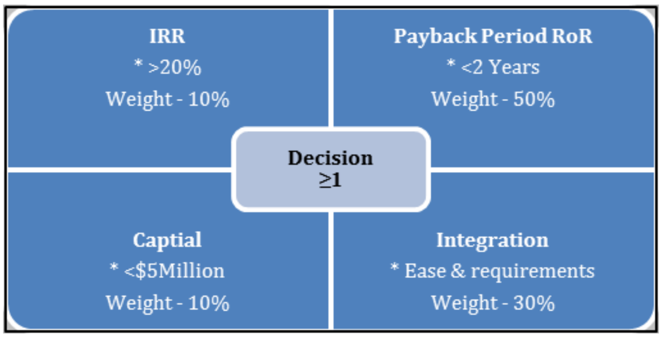
Key investment hurdles include:

- payback period RoR of less than two years
- CAPEX less than $5M
- IRR >20%.

Each of these items, if met, would score 2. If only 90% met, they would score 1. If less than 90% is met, a score of 0 is applied.

Additionally, integration of the unit is crucial and has the following rating system:

- 2 – compact, modular, limited disruption to existing facility
- 1 – modifications or additional housing required
- 0 – complete new layout required or major disturbance to existing facility.



A weighting was then applied based on the relative importance to Plant D's operators in terms of investment decisions. There were:

- RoR, as the most important element, gained a 50% loading.
- Integration in the existing plant, as second most important, garnered a 30% weighting.
- IRR and NPV, as the lesser considerations, were allocated a 10% weighting each.

The overall score becomes a product of the individual scores and weightings, with a score > 1.5 likely to be rated an 'investment-ready' project for Plant D.

A score of 1 indicates an attractive project to commercial investors, but it is not attractive enough to demand capital from Plant D without coincident overhaul works.

Scores of less than 1 are considered unviable commercially and unattractive to Plant D without coincident major overhaul works.

3.4 Technology Investment Results

3.4.1 Cogeneration Turbine

From the economic analysis, the cogeneration turbine is one of the least attractive investments with a high capital investment and a long payback period, along with a difficult integration process into the current facility operations.

However, during a major overhaul or maintenance/replacement project, a cogeneration turbine may provide a far more attractive result, as much of the capital expenditure would directly replace other expenditure. Additionally, the integration aspects would be simpler given major overhaul was already underway. This is therefore not a definitive result for this site. It just indicates that a turbine would be expensive and challenging to integrate into an existing facility.

AMPC - Heat Recovery: Economic Outlook Analysis

Turbine

Summary Table

Year	Capital Outlay	O&M*	Energy Revenue	REC Revenue
2014/15	$ 5,400,000	$ 314,329	$ -	$ -
2015/16	$ -	$ 35,166	$ 1,526,129	$ 278,486
2016/17	$ -	$ 35,166	$ 1,588,426	$ 286,841
2017/18	$ -	$ 35,166	$ 1,653,265	$ 295,446
2018/19	$ -	$ 385,956	$ 1,720,752	$ 304,309
2020/21 to 2040/41 + escalation per annum	$ -	$ 2,457,270	$ 53,788,379	$ 8,422,216
Please note that over the O&M lifetime of the unit, $0.5M has been included to cover replacements & overhauls.				

25 year revenue	$ 60,276,951.44
25 year RECs Revenue	$ 9,587,298.59
Total Revenue over 25 years	**$ 69,864,250.03**
Total Capital Years 1-5	**$ 5,400,000.00**
NPV at Year 25	**$ 9,924,367.58**
IRR over 25 Year Period	**12.10%**
Payback Period in Years	**9**

DECISION MAXTRX

Turbine	Weight	Points	**Weighted**
IRR	10%	0	**0**
CAPEX	10%	1	**0.1**
Payback Period	50%	0	**0**
Integration	30%	0	**0**
	TOTAL:	1	0.1

3.4.2 Cogeneration Engine

A cogeneration engine provides strong IRR results of ~23%; however, it is difficult to integrate and requires a significant capital expense of well over $5M for the engine to have the capacity and capability to generate electricity and heat to meet Plant D's needs.

However, during a significant site overhaul this option may be more attractive.

AMPC - Heat Recovery: Economic Outlook Analysis

Engine

Summary Table

Year	Capital Outlay	O&M*	Energy Revenue	REC Revenue
2014/15	$ 6,400,000	$ 92,973	$ -	$ -
2015/16	$ -	$ 95,762	$ 1,529,051	$ 278,486
2016/17	$ -	$ 98,635	$ 1,592,990	$ 286,841
2017/18	$ -	$ 101,594	$ 1,659,603	$ 295,446
2018/19	$ -	$ 104,642	$ 1,729,001	$ 304,309
2020/21 to 2040/41 + escalation per annum	$ -	$ 1,804,761	$ 54,661,335	$ 8,422,216

Please note that over the O&M lifetime of the unit, $0.3M has been included to cover replacements & overhauls.

25 year revenue	$ 61,171,980.43
25 year RECs Revenue	$ 9,587,298.59
Total Revenue over 25 years	**$ 70,759,279.02**

Total Capital Years 1-5	**$ 6,400,000.00**

NPV at Year 25	**$ 33,152,431.99**
IRR over 25 Year Period	**23.14%**
Payback Period in Years	**5**

DECISION MAXTRX

Engine	Weight	Points	**Weighted**
IRR	10%	2	**0.2**
CAPEX	10%	0	**0**
Payback Period	50%	0	**0**
Integration	30%	1	**0.3**
	TOTAL:	**3**	**0.5**

3.4.3 Absorption Chiller

Exhaust

An absorption chiller operating off the flue stack exhaust gases is a low investment cost option that delivers a commercially attractive seven-year RoR. However, for Plant D, the lengthy payback period of the investment makes the investment unviable.

The relatively difficult integration also means that a small project like this would have significant project risks.

AMPC - Heat Recovery: Economic Outlook Analysis

Absorption Chiller - Exhaust

Summary Table

Year	Capital Outlay	O&M*	Energy Revenue	REC Revenue
2014/15	$ 329,919	$ 27,265	$ -	$ -
2015/16	$ -	$ 28,083	$ 73,256	$ -
2016/17	$ -	$ 28,926	$ 83,597	$ -
2017/18	$ -	$ 29,793	$ 87,359	$ -
2018/19	$ -	$ 30,687	$ 91,290	$ -
2020/21 to 2040/41 + escalation per annum	$ -	$ 529,266	$ 2,992,784	$ -

Please note that over the O&M lifetime of the unit, $0.1M has been included to cover replacements & overhauls.

25 year revenue	$ 3,328,286.80
25 year RECs Revenue	$ -
Total Revenue over 25 years	**$ 3,328,286.80**
Total Capital Years 1-5	**$ 329,918.77**
NPV at Year 25	**$ 1,299,613.92**
IRR over 25 Year Period	**18.74%**
Payback Period in Years	**7**

DECISION MAXTRX

Absorption Chiller - Exhaust	Weight	Points	Weighted
IRR	10%	1	**0.1**
CAPEX	10%	2	**0.2**
Payback Period	50%	0	**0**
Integration	30%	1	**0.3**
	TOTAL:	**4**	**0.6**

Waste Heat

The waste heat absorption chiller suffers from the same issues as the exhaust-based flue stack absorption chiller, compounded by additional capital expense and operational costs related to operating a waste heat (water or steam) absorption chiller compared to the exhaust gas chiller.

As a result, it becomes less viable than a flue gas absorption chiller.

AMPC - Heat Recovery: Economic Outlook Analysis

Absorbtion Chiller - Waste Heat

Summary Table

Year	Capital Outlay	O&M*	Energy Revenue	REC Revenue
2014/15	$ 370,716	$ 30,637	$ -	$ -
2015/16	$ -	$ 31,556	$ 73,256	$ -
2016/17	$ -	$ 32,503	$ 83,597	$ -
2017/18	$ -	$ 33,478	$ 87,359	$ -
2018/19	$ -	$ 34,482	$ 91,290	$ -
2020/21 to 2040/41 + escalation per annum	$ -	$ 594,714	$ 2,992,784	$ -

Please note that over the O&M lifetime of the unit, $0.1M has been included to cover replacements & overhauls.

25 year revenue	$ 3,328,286.80
25 year RECs Revenue	$ -
Total Revenue over 25 years	**$ 3,328,286.80**
Total Capital Years 1-5	**$ 370,715.98**
NPV at Year 25	**$ 1,207,879.62**
IRR over 25 Year Period	**16.64%**
Payback Period in Years	**7**

DECISION MAXTRX

Absorbtion Chiller - Waste Heat	Weight	Points	**Weighted**
IRR	10%	0	**0**
CAPEX	10%	2	**0.2**
Payback Period	50%	0	**0**
Integration	30%	1	**0.3**
	TOTAL:	**3**	**0.5**

Steam Turbine

Further background research into the parameters required for the successful operation of steam turbines readily available from the market identified some significant and unresolvable hurdles in installing a steam turbine in this application.

The key flaw is that the steam pressures generated at Plant D are not sufficient to operate a commercial steam turbine.

A steam turbine is not a viable addition without the generation of additional ‘high quality’ steam that isn’t utilised anywhere on this site.

The cost to generate ‘high quality’ steam and install a steam generator will not deliver a positive IRR or NPV, thus the RoR cannot be calculated, as the investment is unlikely to ever return the capital expense.

Organic Rankine Cycle (ORC) Generator

The ORC heat recovery unit utilises the waste heat of any form (water, steam, exhaust) to produce electricity. This hybrid capability ensures that ORCs are widely applicable to industries that utilise heat and power.

ORCs are quite compact, but do also tend have quite small-scale electrical output. The unit reviewed was rated at an electrical output of 125kW and, as a result the small scale, when compared to the capital expense resulted in a lengthy payback period.

Larger electrical output ORC units are not commercially available at this time.

AMPC - Heat Recovery: Economic Outlook Analysis

ORC Recovery Unit - Steam

Summary Table

Year	Capital Outlay	O&M*	Energy Revenue	REC Revenue
2014/15	$ 600,000	$ 49,585	$ -	$ -
2015/16	$ -	$ 51,073	$ 58,699	$ 11,590
2016/17	$ -	$ 52,605	$ 66,985	$ 11,938
2017/18	$ -	$ 54,183	$ 69,999	$ 12,296
2018/19	$ -	$ 55,809	$ 73,149	$ 12,665
2020/21 to 2040/41 + escalation per annum	$ -	$ 962,539	$ 2,398,064	$ 350,525

Please note that over the O&M lifetime of the unit, $0.1M has been included to cover replacements & overhauls.

25 year revenue	$ 2,666,896.47
25 year RECs Revenue	$ 399,014.24
Total Revenue over 25 years	**$ 3,065,910.71**
Total Capital Years 1-5	**$ 600,000.00**
NPV at Year 25	**$ 594,402.73**
IRR over 25 Year Period	**8.51%**
Payback Period in Years	**12**

DECISION MAXTRX

ORC Recovery Unit - Steam	Weight	Points	Weighted
IRR	10%	0	**0**
CAPEX	10%	2	**0.2**
Payback Period	50%	0	**0**
Integration	30%	2	**0.6**
	TOTAL:	**4**	**0.8**

Micro-Turbine Cogenerator

The micro turbines studied are fully self-contained, modular and expandable, based on a 200kW package module. The turbine comes with a bolt-on heat recovery system, so it is ideally suited to retrofitting existing meat processing facilities.

They are also highly suited as a supplementary firing system to allow facility growth.

The micro turbines scored highly on the IRR, capital spend and NPV elements, but could only deliver an ROR of five years, thus had critical failings for Plant D investment in the heaviest weighted area.

From a pure investment perspective, it is apparent that there are commercial hire-purchase options and vendor financing capabilities to complement capital raising within meatworks and avoid capital-sourcing competition with other faster RoR projects.

Micro turbines have numerous attractive applications in meat processing facilities; however, some more creative financing solutions are needed to realise those opportunities.

AMPC - Heat Recovery: Economic Outlook Analysis

Micro-Turbine

Summary Table

Year	Capital Outlay	O&M*	Energy Revenue	REC Revenue
2014/15	$ 2,700,000	$ -	$ -	$ -
2015/16	$ -	$ 8,593	$ 635,887	$ 92,829
2016/17	$ -	$ 8,851	$ 661,844	$ 95,614
2017/18	$ -	$ 9,117	$ 688,861	$ 98,482
2018/19	$ -	$ 9,390	$ 716,980	$ 101,436
2020/21 to 2040/41 + escalation per annum	$ -	$ 259,886	$ 22,411,825	$ 2,807,405
Please note that over the O&M lifetime of the unit, $0.1M has been included to cover replacements & overhauls.				

25 year revenue	$ 25,115,396.43
25 year RECs Revenue	$ 3,195,766.20
Total Revenue over 25 years	**$ 28,311,162.63**

Total Capital Years 1-5	**$ 2,700,000.00**

NPV at Year 25	**$ 14,200,310.57**
IRR over 25 Year Period	**23.63%**
Payback Period in Years	**5**

DECISION MAXTRX

Micro-Turbine	Weight	Points	**Weighted**
IRR	10%	2	**0.2**
CAPEX	10%	2	**0.2**
Payback Period	50%	0	**0**
Integration	30%	2	**0.6**
	TOTAL:	**6**	**1**

4.0 Conclusion

None of the heat recovery options reviewed for Plant D met the investment hurdles of the site owner/operator.

However, there is clear merit in the emerging micro-turbine cogenerator technology and potential for ORC technology to deliver larger power outputs, making them far more attractive.

A key learning from this research is that many major investments in heat recovery need to be delivered during overhauls or major maintenance change-out works, where investment is already underway and can be diverted to cogeneration works. Such cogeneration works will be a far more attractive proposition than simple boiler replacement at the change-out site.

Retrofit of major plant such as boilers with cogeneration equipment, prior to the end of their effective life, is simply an unviable exercise in an environment where competition for capital is fierce.

The researchers do not foresee a need to further research large turbine or engine-based cogenerators, given they are a well-developed commercialised technology.

4.1 Future Research in Modular Cogenerators

This body of work has identified research into compact modular units such as micro turbines and ORC units as a priority for the red meat processing industry.

The key benefits of micro turbines and ORC units include:

- Relatively attractive financial results
- Modularity
- Flexibility
- The ability to be incorporated into overhauls and plant capacity upgrades on a progressive basis without major capital injection.